Appendix I

Numerical Model

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HARPER LAKE BASIN NUMERICAL GROUNDWATER MODELING STUDY HINKLEY, CALIFORNIA

Prepared For:

MOJAVE SOLAR, LLC

JULY 2009

LGS PROJECT NO. 27-1643

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TABLE OF CONTENTS

SECTION **PAGE**

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICIES

STANDARD LIST - GLOSSARY OF TERMS AND ABBREVIATIONS

alluvium: Unconsolidated terrestrial sediment composed of sorted or unsorted sand, gravel, and clay that has been deposited by water

aquifer: An underground geological formation, or group of formations, containing water; are sources of groundwater for wells and springs.

ARM: Absolute Residual Mean

bgs: Below ground surface

conductance: A numerical parameter used by MODFLOW to calculate the leakage between a model boundary and the aquifer

confined aquifer: A fully saturated aquifer overlain by a low-permeability layer of sediment or rock. The hydraulic head of the water in a confined aquifer is at an elevation equal to or greater than the base of the overlying confining layer.

DEM: Digital Elevation Models

drawdown: The drop in the water table or level of water in the ground when water is being pumped from a well

ET (evapotranspiration): The combined process of evaporation and transpiration; evaporation is the process whereby liquid water is converted to water vapor (vaporization) and removed from the evaporating surface; transpiration consists of the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere

finite-difference: A numerical method that solves a set of partial differential equations using approximation techniques

FIPS: Federal Information Processing Standard

flood plain: The flat or nearly flat land along a river or stream or in a tidal area that is covered by water during a flood

fluvial deposit: A geologic material deposited by processes associated with rivers and streams

ft msl: Feet above mean sea level.

geo-referenced: Technique applied to digital images to link the image to a specific coordinate system

GHB: General Head Boundary

gpm: Gallons per minute

hydraulic conductivity (K): The rate at which water can move through a permeable medium (i.e., the coefficient of permeability)

hydrogeology: The geology of ground water, with particular emphasis on the chemistry and movement of water

igneous: Rocks formed by the cooling and solidification of molten silicate minerals (magma); includes intrusive and extrusive types

impermeable: Not easily penetrated; the property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water

lacustrine deposit: A material deposited from processes associated with lakes

metamorphic: A rock formed of pre-existing sediments that have been altered by changes in pressure or temperature

MODFLOW: Groundwater flow model developed by McDonald and Harbaugh (1988)

NAD83: North American Datum of 1983

NAVD: North American Vertical Datum

NRMS: Normalized root mean square

permeability: The rate at which liquids pass through soil or other materials in a specified direction

Pleistocene: An epoch of the Quaternary period, spanning the time between 1.8 million years ago and the beginning of the Holocene at 10,000 years ago

pluvial deposit: A material deposit associated with an ancient lake in a desert climate

potentiometric surface: The surface to which water in an aquifer can rise by hydrostatic pressure

Quaternary: The second period of the Cenozoic Era, beginning two to three million years ago and continuing to the present

recharge : The quantity of water per unit of time that replenishes or refills an aquifer

telescoping grid mesh: A variable-size model grid which uses large cells on the edges of the model and smaller cells within the area of interest of the model

Tertiary Period: A geologic period that marks the beginning of the Cenozoic Era, spanning from 65 million to 1.8 million years ago

unconfined aquifer: An aquifer containing water that is not under pressure; the water level in a well is the same as the water table outside the well

USGS: U.S. Geological Survey

1 INTRODUCTION

This report presents the results of a numerical groundwater flow model (groundwater model) developed in support of the Basin Conceptual Model report (BCM) for the proposed Mojave Solar Project (MSP) and is submitted as an appendix to the BCM (LGS, 2009). The groundwater model incorporates significant hydrogeologic features associated with the Harper Lake groundwater basin (Basin), which is located near Hinkley, California. The groundwater model uses Basin hydrogeologic information presented within the BCM. Accordingly, the groundwater model incorporates newly acquired information, including geophysical data interpretations associated with the geometry of the Black Mountain basalt and site-specific aquifer parameters obtained from an aquifer pumping test conducted within the MSP area. An interpretation by Crosby of historical gravity data (Crosby, 1990) was used to better understand variability of the top of the basement rock elevations within the Basin.

1.1 MODEL PURPOSE

The purpose of the groundwater model presented in this document was to develop a tool that can be used as a “conceptual calculator” to evaluate:

- Basin recharge;
- Hydraulic interference generated by MSP groundwater production during the 26 month construction phase; and
- Hydraulic interference generated by MSP groundwater production during the 30-year production phase.

This document provides a general discussion of the groundwater modeling and describes the analyses, conclusions developed, and is organized as follows:

- **<u>Section 2</u>** – Conceptual Model
- **<u>Section 3</u>** – Groundwater- Model Construction
- **<u>Section 4</u>** – Groundwater-Model Calibration
- **<u>Section 5</u>** – Sensitivity Analysis
- **<u>Section 6</u>** – Predictive Analysis
- **<u>Section 7</u>** – Conclusions

2 CONCEPTUAL MODEL

Construction of a groundwater flow model capable of estimating the impact of future changes within a groundwater basin requires an understanding of the overall hydrogeologic system within the basin. Accordingly, we reviewed existing information and collected new data to improve knowledge of Basin hydrology and hydrogeology. The referenced information and data were presented in the BCM and is the basis for this document.

3 GROUNDWATER MODEL CONSTRUCTION

The model area was selected to include the physical aquifer boundaries and significant hydrologic features of the Basin. The numerical model builds upon the hydrogeologic framework presented in the BCM, and includes the following hydrogeologic features: Harper Dry Lake; the Helendale, Lockhart, and Iron Mountain faults; Iron Mountain; Lynx Cat Mountain; the Hinkley Gap; various unnamed plutons; and the alluvial valley of the Mojave River. The model covers approximately 735 square miles and was constructed on a telescopic grid with cell sizes as small as 100 feet by 100 feet in the vicinity of Harper Dry Lake (Figure 3-1). To best represent the layered geology observed within the study area, the model was constructed using three (3) layers. The first layer (Layer 1) represents the upper Quaternary-age unconsolidated aquifer above the basalt flow, as described in the BCM. Layer 2 represents the Black Mountain basalt in the northeast portion of the model domain. Where the basalt is absent, Layer 2 has the same properties as Layer 3 (lower unconsolidated aquifer). Layer 3 represents the lower Quaternary-age unconsolidated fluvial deposits as described in the BCM. The bottom of Layer 3 is the base of the model and represents the top of competent bedrock. The bottom of Layer 3 was developed using the historical gravity-based geophysical mapping (Crosby, 1990) discussed within the BCM. Once completed, the model contained 289 rows, 339 columns, and three layers for a total of 293,913 model cells (209,803 active cells).

3.1 MODEL CODE

Code selection for the numerical model was based on the following criteria:

- Is the code accepted by the engineering and regulatory communities?
- Has the accuracy of the code been verified by comparing the results with one or more analytical solutions?
- Does the code include a water-balance computation?
- Has the code been used in other field studies?
- Can the code account for anisotropy, heterogeneity, and three-dimensional flow?

The computer code MODFLOW (McDonald and Harbaugh, 1988), version MODFLOW-96, was selected for this project because it satisfied all of the above requirements. MODFLOW is a finite-difference, block-centered model that simulates three-dimensional groundwater flow in saturated porous media. MODFLOW was developed to include a modular structure, allowing different hydrologic systems and stresses to be grouped together to simulate the modeled area. MODFLOW was selected for use in this modeling study because of its wide use and acceptance by the engineering and regulatory communities.

3.1.1 MASS- BALANCE CALCULATION

The mass-balance calculation checks the amount of residual error in the solution by comparing the total simulated inflows and outflows. Reviewing the mass-balance error is a critical technique for checking the accuracy of the model solution, and the inclusion of a mass-balance calculation was a primary reason that the MODFLOW code was chosen. The water-balance error is calculated by subtracting the total inflow from the total outflow and dividing the difference by either the total inflow or total outflow, whichever yields the highest error. A water-balance error of one (1) percent is considered acceptable (Anderson and Woessner, 1992). In addition to checking the solver accuracy, the water-balance calculation can be used to identify errors made during model design. For example, failure of the model to reach a solution or a solution with a high water-balance error could indicate errors in data entry or an invalid conceptual model.

3.1.2 DATA-PROCESSING SOFTWARE

Construction of the numerical model and evaluation of model-predicted output were done using Groundwater Vistas Version 5 (Rumbaugh, 2004). Groundwater Vistas is a pre- and post-processing software package that was used to create standard-format MODFLOW file sets from graphically input data.

Model output was evaluated using Groundwater Vistas, Surfer® Version 8 (Golden Software, 2002), ESRI ArcView 9.2, and Microsoft Excel. Groundwater Vistas was used when possible to provide contoured model results (model-predicted heads and drawdown) and numerical data output. Additional data contouring and evaluation was completed using Surfer®. Surfer® is a grid-based contouring and three-dimensional surface-plotting program. Surfer® and ArcView 9.2 were used to interpolate the irregularly spaced model-predicted data onto regularly spaced grids and to produce contoured results.

3.2 MODEL LAYERS

The following section provides details on the construction of the model layers. The modeled aquifer is a complicated system which includes a combination of: lacustrine/pluvial sediments, fluvial deposits, and alluvial fans. Adding to the complexity of the geology within the Basin is the presence of the Pleistocene-age Black Mountain basalt flow, which acts as an aquitard where present, and the highly variable elevations of the top of competent basement rock, which forms the bottom of the aquifer system. To best reproduce the hydrogeology of the Basin, the following three layers were created:

- Layer 1 – Represents the upper Quaternary-age unconsolidated aquifer above the basalt flow, as described in the BCM. The top of Layer 1 was imported into the model using a digitized elevation model (DEM) of the ground surface. The bottom of Layer 1 is represented by the top of Layer 2 and more specifically by the basalt flow, where it is present.

- Layer 2 – Basalt layer in the northeast portion of the model domain. Where the basalt is absent, Layer 2 has the same properties as Layer 3. The top elevation of the basalt unit is variable and was assigned based on the geophysical data presented in the BCM. Layer 2 was assigned a uniform thickness of 100 feet based on the geologic cross sections presented in the BCM.
- Layer 3 - Represents the lower unconsolidated aquifer as described in the BCM. The bottom of Layer 3 was developed using the historical gravity-based mapping (Crosby, 1990) discussed within the BCM.

The only field test available to characterize the hydraulic properties of the various layers was an aquifer pumping test conducted in Layer 1, which provides an average value of the hydraulic properties of the aquifer over the tested interval. No discrete interval tests (slug tests, permeameter tests, etc.) were available to assign different hydraulic property values to Layer 2 and Layer 3. The hydraulic properties assigned to Layer 2 and Layer 3 were obtained from previous studies conducted near the model area by others, or from literature.

3.2.1 UPPER UNCONSOLIDATED AQUIFER – LAYER 1

Model Layer 1 represents the shallow Quaternary-age sediments that generally consist of fluvial deposits, lucustrine sediment, and reworked lacustrine sediment from the ancestral Mojave River. This model layer is the hydrogeologic unit where groundwater is first encountered in the Basin. MSP groundwater production will be from the aquifer represented by Layer 1.

The upper surface of Model Layer 1 is the ground surface. To accurately duplicate the ground surface within the study area, a ground-surface elevation file was created. The ground-surface elevation input data were generated from a Digital Elevation Model (DEM). A DEM is a sampled array of elevations for a number of ground positions spaced horizontally at regular intervals. The DEMs used for this study were developed by the United States Geological Survey (USGS). Their elevation data are generated from hypsography digital line graphs that have been smoothed for consistency and edited to remove identifiable systematic errors. Each DEM file corresponds to a USGS 7.5-minute topographic quadrangle map and consists of elevation data spaced evenly across the quadrangle at 30-meter intervals. The DEMs are referenced horizontally to Universal Transverse Mercator (UTM) projections and have a root-mean-square error of one-half the contour interval (5 feet). DEMs were downloaded for each of the USGS 7.5-minute topographic quadrangle maps falling with the study area. The DEM files were assembled using ArcView 9.2, and the projection of the DEM files was converted to California State Plane (NAD1983, California FIPS V). The resulting file was imported into the modeling pre-processor and represents the top of Layer 1.

3.2.2 BLACK MOUNTAIN BASALT - LAYER 2

Model Layer 2 includes a representation of the early Pleistocene-age Black Mountain basalt layer. This basalt layer is present in the northeast portion of the model domain (Figure 3-2). Where present, the basalt unit is an important hydrogeologic feature within the Basin as it acts as a low-permeability aquitard separating the two unconsolidated aquifers.

The top of Layer 2 (also the bottom of Layer 1) was imported as an elevation file and includes information based upon results of the geophysical field program implemented by LGS. The results of the geophysical surveys are presented in the Harper Lake Basin Geophysical Surveys report, prepared by LGS and included as BCM Appendix H. As a simplification, Layer 2 was assigned a uniform thickness of 100 feet which is consistent with BCM information. In areas outside of the assessed extents of the Black Mountain basalt flow, the hydraulic properties of Layer 2 were set equal to those in Layer 3, effectively eliminating the confining unit in these areas of the model domain.

3.2.3 LOWER UNCONSOLIDATED AQUIFER - LAYER 3

Model Layer 3 represents the lower Quaternary-age aquifer, below the basalt flow. The top of this unit equals the bottom of Layer 2.

3.2.4 BASE OF MODEL – TOP OF BEDROCK SURFACE

The lower surface of the model is the top of the competent bedrock, as discussed within the BCM. Basin basement rock consists of undifferentiated igneous and metamorphic rocks of pre-Tertiary age. The bedrock-surface elevation used in the groundwater model is variable and includes the plutons (and other rocks) which are exposed above ground surface. The modeled bedrock surface is presented on Figure 3-3.

3.3 MODEL BOUNDARY CONDITIONS

Correct selection of boundary conditions is a critical step in model design. The model domain incorporates the real-world physical boundaries of the aquifer, when possible, to minimize the need for the use of hydraulic category or distant boundaries. It is generally desirable to extend the model boundaries to incorporate the real-world physical boundaries of the aquifer. However, other than the obvious no-flow boundaries which surround the Basin, there are no physical aquifer boundaries, such as perennial streams, for use in model construction.

Simulation of a groundwater basin requires characterization of the sources and sinks within the basin. Because no obvious surface-water source boundaries are available, a review of historic potentiometric-surface elevation maps was performed to evaluate the potential sources of groundwater to the basin. A pre-development potentiometric surface map constructed by the USGS using groundwater observations collected in the 1920s and 1930s was used as the conceptual model to assign boundary conditions for the numerical simulations (Hardt, 1971). The pre-development potentiometric surface map is included as Figure 3-4.

Based on the review of pre-development groundwater flow conditions, the alluvial aquifer immediately adjacent to the Mojave River was identified as the primary source of water and recharge to the aquifers in the Harper Lake Basin. In this area of the Mojave River alluvial aquifer, the groundwater hydraulic head is as much as 200 to 300 feet higher than the groundwater potentiometric surface observed near Harper Dry Lake.

Based on that review, Harper Dry Lake was identified as the primary sink through which water exited the Basin. During the 1920s and 1930s, measured depths to groundwater as shallow as 10 feet below ground surface were common near Harper Dry Lake (Thompson, 1929). As part of the model construction, the hydrogeologic features described above and discussed within the BCM were simulated as follows:

- Harper Dry Lake – Drain Boundary;
- The Helendale, Lockhart, and Iron Mountain faults – Horizontal Flow Barriers;
- Iron Mountain and Lynx Cat Mountain – No-Flow Boundary;
- Unnamed plutons – No-Flow Boundaries; and
- The Mojave River alluvial valley – General Head Boundary.

The numerical model boundary conditions are presented on Figure 3-5.

3.3.1 GENERAL HEAD BOUNDARY PACKAGE

A General Head Boundary (GHB) package was selected to simulate the location of the elevated potentiometric surface within the Mojave River alluvial aquifer. With a GHB, the flux into or out of the model is controlled by the difference in head across the model boundary and the conductance across the model boundary. Data input includes boundary location, boundary head, and boundary conductance. These input values allow the modeler to adjust the boundary conditions until the model accurately simulates the groundwater flow gradient (magnitude and direction) observed. A complete description of the General Head Boundary Package can be found in chapter eleven of the MODFLOW manual (McDonald and Harbaugh, 1988).

Water flows into and out of the GHB-package cells at a rate proportional to the difference in head within the aquifer and the assigned elevation of the head in the GHB cell as follows:

$$Q = C * (h_b - h),$$

where

Q	=	rate at which water is removed from the drain cell (L^3/T),
C	=	boundary conductance (L^2/T),
h_b	=	simulated head in the aquifer (L), and
h	=	specified head at the boundary (L).

The conductance term represents the resistance to flow between the boundary and the aquifer and is calculated using the following formula:

$$C = \frac{K * L * W}{M},$$

where

C = conductance of the interface between the aquifer cell and the boundary (L^2/T),

K = vertical conductivity (L/T),

L = length of the model cell (L),

W = width of the model cell (L), and

M = saturated thickness of the cell (L).

As a point of departure for model calibration, the length and width in the conductance term were set equal to the model grid size, the vertical hydraulic conductivity (K_z) was set equal to 0.2 feet/day, and the saturated thickness of the cell was set equal to one (1) foot. The elevation of the GHB was set equal to the measured potentiometric surface in the Mojave River alluvial aquifer, as shown on Figure 3-4. Simulating the elevated potentiometric surface of the Mojave River alluvial aquifer as a GHB is an approximation of observed field conditions, and provides a constant source of water to the Basin. Historical potentiometric surface maps and information presented within the BCM support this approach.

As previously stated, boundary head elevations for the GHB cells were based on the pre-development potentiometric surface map developed by the USGS, presented as Figure 3-4. Because the boundary head measurements were measured in the field, the boundary head data were not modified during the model calibration process. Rather, the model calibration focused on modifying the conductance term until an acceptable match to the pre-development measured potentiometric surface was obtained.

It should be noted that in the description of the River Package, Chapter Six of the MODFLOW Manual (McDonald and Harbaugh, 1988), the author states:

> "It should be recognized that formulation of a single conductance term to account for a three-dimensional flow process is inherently an empirical exercise, and that adjustment during calibration is almost always required."

This statement identifies the need for determining conductance through the model-calibration process. Field measurements are used as a point of departure in calibrating boundary conductance values; however, the final boundary conductance values are selected based on the model calibration. This statement is true for GHB conditions as well as River Boundary conditions.

3.3.2 Drain Package

The MODFLOW Drain Package was used to simulate the impact of Harper Dry Lake on the hydrogeologic system of the Harper Lake Basin. This package allows water to discharge at the dry lake when the simulated hydraulic head in the aquifer is greater than the specified elevation of the drain. In a drain boundary, water is removed from the aquifer at a rate proportional to the difference in head within the aquifer and the assigned elevation of the drain as follows:

$$Q = C * (h - d),$$

where

Q = rate at which water is removed from the drain cell (L^3/T),

C = drain conductance (L^2/T),

H = simulated head in the aquifer (L), and

D = specified drain elevation (L).

Water is not removed from the aquifer if the head in the aquifer drops below the assigned drain elevation. The locations of the drain cells are shown on Figure 3-5. The elevations of the drain cells in the model were set equal to the average elevation of the surface of Harper Dry Lake, which is approximately 2,020 feet above mean sea level (ft msl).

Because the drain elevation is a physically measured value, it was not modified during the model calibration process. Rather, the model calibration focused on modifying the conductance term until an acceptable match to the pre-development measured potentiometric surface was obtained. A complete description of the Drain Package can be found in chapter nine of the MODFLOW manual (McDonald and Harbaugh, 1988).

3.3.3 No-Flow Boundaries

Mathematically, no-flow boundaries occur when flux across a model cell is set to zero. Therefore, no-flow boundaries are generally used to simulate impermeable boundaries, groundwater divides, or streamlines. No-flow boundaries were used specifically in this groundwater model to represent the contacts of the unconsolidated aquifer with consolidated deposits. Consolidated deposits are not impermeable; however the quantity of water contributed from the consolidated deposits to the unconsolidated aquifers is likely negligible, which allows for the use of no-flow boundaries to simulate these consolidated materials.

The location of no-flow boundary cells is shown on Figure 3-5. No-flow cells were placed to represent the outcrops of metamorphic and igneous rocks which border the Basin. No-flow boundaries were also positioned to simulate Iron Mountain and Lynx Cat Mountain.

The base of the model is the top of the basement rock and this is represented in the model as a no-flow boundary. Generally, a difference in hydraulic conductivity of two orders of magnitude is sufficient to justify the placement of an impermeable boundary (Anderson and Woessner, 1992).

3.3.4 Horizontal Flow Barrier

Many faults transect the Harper Lake Basin. Of these, three (3) were found to have a significant effect of the groundwater flow system: the Helendale, Lockhart, and Iron Mountain faults. These faults were simulated using the Horizontal Flow Barrier package (HFB), which allows simulation of a thin, vertical, low-permeability feature that impedes horizontal flow through a model layer. HFBs are defined by the hydraulic characteristic of the fault, which is defined as the hydraulic conductivity of the fault divided by the width of the model cell. The hydraulic characteristic of the faults in the groundwater flow model ranged from 2 $x10^{-4}$ feet squared per day (ft^2/day) for the Iron Mountain fault to 1 $x10^{-8}$ ft^2/day for the Helendale fault. These values were obtained through the calibration process.

3.3.5 EVAPOTRANSPIRATION PACKAGE

Due to the depth of groundwater within the study area, no evaporation or transpiration was simulated.

3.3.6 RECHARGE PACKAGE

Recharge from precipitation was not simulated. The model's total Basin recharge includes input from precipitation and underflow (see BCM Tables 4-3a and 4-3b).

3.3.7 PCG2 SOLVER PACKAGE

The Preconditioned Conjugate Gradient 2 (PCG2) Package defines the finite-difference solution technique used to solve the flow equations for the numerical model. The PCG2 solver is a program for solving the large system of matrix equations produced by MODFLOW. The PCG2 solver was selected for the numerical model because convergence of the solver is determined using both head change and residual criteria, meaning that one of the convergence criteria for PCG2 is related to the water budget. A complete description of the PCG2 solver can be found in USGS Water Resources Investigations Report 90-4048 (USGS, 1990).

4 GROUNDWATER MODEL CALIBRATION

This section describes the goals and methods of calibrating the numerical model, which is defined as "finding a set of parameters, boundary conditions, and stresses that produce simulated heads and fluxes that match field-measured values within a pre-established range of error" (Anderson and Woessner, 1992).

4.1 MODEL CALIBRATION OBJECTIVES

The model calibration was evaluated using the following methods:

- Statistical paired data testing of water-level measurements collected from the aquifer (head targets);
- A visual comparison of the model predicted and observed potentiometric surface;
- A comparison of model predicted and total estimated recharge to the Basin, as presented in the BCM; and
- Observation of the model's ability to reproduce the drawdown measured in the observation well during the Ryken-well aquifer test.

The first three (3) calibrations were performed assuming steady-state conditions while the Ryken-well aquifer-test simulation was performed assuming transient conditions. For the model calibration, it was assumed that the pre-development water levels measured in the 1920s and 1930s, as presented by the USGS, represented a quasi-steady-state condition, under the limited aquifer stresses which were occurring during that time period.

For the paired data testing, the model-predicted water levels were compared to the observed water levels. To evaluate the model calibration, normalized root-mean-square (NRMS) error was calculated for each model run and compared to the calibration goal. The steady-state calibration goals for the numerical model were as follows:

1. A water-balance error of less than one (1) percent, which is considered appropriate for a calibrated groundwater model (Anderson and Woessner, 1992). The water-balance error is defined as the total inflow minus the total outflow, divided by either the inflow or outflow, whichever yields the highest error.
2. A NRMS of less than five (5) percent. A NRMS of less than five (5) percent is generally considered appropriate for a calibrated groundwater model. A lower NRMS indicates a better statistical model calibration. The NRMS can be described as the standard deviation of the residuals divided by the observed range of head values.
3. An Absolute Residual Mean (ARM) error of less than 10 feet, which is approximately equal to 5 percent of the observed range of head targets. The

ARM can be described as the average error of the absolute value of the residuals.

4. Random error distribution. A plot of the residual vs. observed value should indicate no obvious trend in the model.
5. A reasonable visual match of the model predicted and observed pre-development potentiometric surface. When calibrated, the model should be able to reproduce the direction and magnitude of the hydraulic gradient observed within the study area.
6. The recharge to the basin predicted by the model should be acceptable and judged reasonable by the Mojave Water Authority.
7. Drawdown at the Hay Farm observation well (Ryken well aquifer pumping test) predicted by the model should differ from that observed at the Hay Farm observation well during the Ryken well aquifer pumping test by no more than 0.5 feet.

4.1.1 CALIBRATION TARGETS

Calibration of a groundwater flow model for the Harper Dry Lake region is a difficult task due primarily to the absence of reliable groundwater elevation data. Complicating matters, the hydrogeologic system near Harper Dry Lake is in a transient state, primarily due to significant change to groundwater withdrawal (pumping) from the regional aquifer over the last 80 to 90 years. Careful examination of groundwater hydrographs near Harper Dry Lake (Stamos et al., 2004) indicates the aquifer was pumped at rates above the safe yield of the system starting before the 1950s and extending through 1980s. The system is now in a period of groundwater recovery, as evidenced through examination of historical hydrographs (Stamos et al, 2004). Because the system is in a state of rebound (or recovery), groundwater elevations collected from wells today are of limited use as steady-state targets for model calibration.

Interpretation of data from the Basin pre-development period (circa 1920) indicate that the potentiometric surface beneath Harper Lake was 10 feet or less, which equates to a potentiometric surface of about 2,020 ft msl. The present-day potentiometric surface elevation is approximately 1,900 ft msl, representing about a 120 foot decline. At the time of maximum decline, the potentiometric surface near Harper Dry Lake dropped below 1,875 ft msl in the early 1990s, indicating about 25 feet of recovery in the last 15 years. This significant change to the potentiometric surface over time and continuing into the future can be described as dynamic hydraulic conditions.

As summarized above, the potentiometric surface near Harper Dry Lake has experienced change within the last century. Accordingly, Basin hydraulic conditions precludes the use of recent groundwater elevation data for use in a steady-state model calibration. Therefore, the steady-state model calibration performed focused on matching the “pre-development” water surface elevation, using data from the 1920s and 1930s. This is similar to the approach adopted by the USGS in calibrating their Mojave River Basin model (Stamos et al., 2001). LGS identified over 30 water-level elevations from this period of record for use as calibration targets as well as a potentiometric surface map of the Mojave River Basin developed by the USGS using data collected in the 1920s and early 1930s (Hardt, 1971). The calibration targets are located in model Layer 1.

A second calibration target for the model is the pre-MSP water budget. Based upon historical literature discussed within the BCM, a reasonable target range for total annual recharge to the Basin (includes precipitation and underflow) is 4,500 to 7,500 acre-feet per year (AFY). Part of the calibration process included checking the mass balance of the model while approximating a match to total Basin recharge and also concurrently minimizing the NRMS error of the steady state calibration targets. As constructed, the mass balance of the model consists of one water source (the General Head Boundary which represents the Mojave River alluvial valley) and two sinks (the Harper Lake Drain and the continuation of the Mojave River alluvial valley represented as a General Head Boundary in the southeast portion of the domain). The model's mass balance focused on comparing the total water entering the system through the General Head Boundary that is necessary to accurately reproduce the observed pre-development potentiometric surface. Model mass balance information was used as the Basin input subtotal for water budgets presented as BCM Tables 4-3a and 4-3b

The third and final calibration consisted of performing transient model runs to reproduce the aquifer pumping test conducted by LGS on the Ryken Well. The results of this aquifer test are summarized in the BCM. The transient calibration focused on matching the model-predicted time-drawdown hydrograph to the measured time-drawdown hydrograph from an observation well located approximately 750 feet from the pumping well. This calibration continued until the model-predicted time-drawdown hydrograph accurately reproduced the observed time-drawdown hydrograph.

4.2 MODEL CALIBRATION

The pre-development water-level calibration targets and the Basin recharge target range was the basis for steady-state model calibration. The pre-development potentiometric surface map of the study area (Hardt, 1971), developed under non-pumping steady-state conditions (Figure 3-4), was the most critical target for the model calibration as it provides a good snapshot of the aquifer conditions prior to 1930. The water-level elevations used to develop this potentiometric-surface map were used to perform paired data testing, which is a statistical comparison of the model-predicted and observed water levels at available observation wells. A visual comparison of the model-predicted potentiometric surface and the observed potentiometric surface served as an additional check of the model's ability to reproduce observed field conditions.

4.2.1 CALIBRATION-PROCESS OVERVIEW

Model calibration is an iterative process in which model input parameters and boundary conditions are modified to improve the statistical calibration results. During the calibration process, input parameters and boundary conditions are varied, one at a time, until the changes cease to improve the statistical results. Model calibration involves modifying model input parameters, one at a time, until all calibration objectives are met. The general model-calibration procedures listed below were used to calibrate the model.

1. Input GHB elevations from the pre-development potentiometric-surface map (Hardt, 1971).
2. Input uniform hydraulic conductivity for Layer 1.
3. Input hydraulic conductivity for Black Mountain basalt in Layer 2.
4. Input uniform hydraulic conductivity for the remainder of Layer 2 and Layer 3.
5. Perform a calibration check to the pre-development data set using the following procedure:
    - Step 1 - Run the model with the pre-development GHB values to represent the groundwater conditions in alluvium of the Mojave River.
    - Step 2 - Evaluate the model calibration data set:
        - Evaluate residual statistics;
        - Evaluate distribution of residuals (error distribution); and
        - Compare model-predicted to observed groundwater gradient.
6. Evaluate the need to modify model input parameters:
    - Compare model-predicted values to calibration objectives 1 through 6.
    - If objectives 1 through 6 are met, non-pumping steady-state calibration is complete.
    - If any of the calibration objectives (1 through 6) are not met:
        - Identify reoccurring errors in the model calibration.
        - Modify model input parameters if reoccurring poor matches are observed in the same spatial location.
        - Modify GHB conductance, Layer-1 hydraulic conductivity distribution, and Drain Boundary conductance values only.
        - Continue until calibration objectives 1 through 6 are met.

4.2.2 CALIBRATED MODEL

The final model calibration is a non-unique solution, meaning the model calibration criteria could likely be satisfied by a different set of input parameters. To minimize the non-uniqueness of the solution, LGS calibrated the model to steady-state water levels, an aquifer pumping test, and estimated recharge into the Basin. Presenting a detailed chronological documentation of the calibration process is not feasible, therefore instead of presenting chronological documentation of the calibration process, we discuss the major varied input parameters below.

4.2.2.1 CONDUCTANCE – GHB PACKAGE

As a point of departure for model calibration, the initial values used for the length and width in the conductance term were set equal to the model grid size, the vertical hydraulic conductivity (K_z) was set equal to 0.2 ft/day, and the saturated thickness of the cell was set equal to one (1) foot. Boundary elevations were not modified during the calibration process. Upon completion of the model calibration, the vertical conductivity value was set to equal 0.4 ft/day. The saturated thickness of the GHB was not modified.

4.2.2.2 HYDRAULIC CONDUCTIVITY DISTRIBUTION

The distribution of hydraulic conductivity/transmissivity for the numerical model was developed from BCM information. Hydraulic conductivity values based on an aquifer pumping-test are considered high quality and accordingly minimal deviations from these values were allowed during the model calibration process. Hydraulic conductivity data for Model Layers 2 and 3 is limited; calibration efforts focused primarily on changing the hydraulic conductivity for Layer 1, outside of the aquifer pumping test area.

As a point of departure for model calibration, the hydraulic-conductivity distribution within each model layer was assumed to be uniform. However, to improve the match between observed and model predicted heads, hydraulic-conductivity "zones" were introduced. The conductivity zones were developed based on the available data and an understanding of fluvial geomorphology. The final modeled hydraulic-conductivity distribution that resulted from the calibration process is presented in Figure 4-1. The final calibrated values for each hydraulic-conductivity zone are presented below.

- Zone 1 – Layer 1 Near Harper Lake – 70 ft/day
- Zone 2 – Layer 2 - Black Mountain Basalt – 0.1 ft/day
- Zone 3 – Layer 2 – Small Area Near Iron Mountain – 10 ft/day
- Zone 4 – Layer 1 - Mojave River Alluvial Valley – 70 ft/day
- Zone 5 – Layer 1 – Area Near Hinkley Gap – 70 ft/day
- Zone 6 – Layers 2 and 3– East of Iron Mountain – 40 ft/day
- Zone 7 – Layers 1, 2, and 3 – West of Iron Mountain – 0.001 ft/day
- Zone 8 – Layer 1 – Small Area East of Iron Mountain – 0.001 ft/day

The ratio of horizontal to vertical hydraulic conductivities (anisotropy ratio K_{xy}:K_z) was not measured in the study area. However, literature sources provide an anisotropic ratio of 10:1 for unconsolidated alluvium (Spitz and Moreno, 1996; Fetter 1994; Freeze and Cherry 1979). Therefore, model-calibration efforts were bracketed between isotropic conditions and an anisotropy ratio of 10:1.

4.2.2.3 <u>CONDUCTANCE – DRAIN PACKAGE</u>

As a point of departure for model calibration, the initial values used for the length and width in the conductance term were set equal to the model grid size, the vertical hydraulic conductivity (K_z) was set equal to 5 ft/day, and the thickness of the drain bed was set equal to 10 feet. Drain elevations were not modified during the calibration process. Upon completion of the model calibration, the vertical conductivity value was set to equal 0.05 ft/day. The thickness of the drain bed was not modified.

4.3 CALIBRATION RESULTS

Upon completion of the model calibration, the statistical paired data testing was evaluated. The results of the final model calibration are as follows:

- A water balance of 0.0001 percent;
- A NRMS 3.2 percent;
- An ARM of 5.0 feet;
- Randomly distributed residual vs. observed value, indicating no bias in model results;
- A good visual match with potentiometric surfaces developed for the study area;
- Model-predicted recharge to the Basin based upon maintaining pre-development hydraulic conditions is 6,530 AFY; and
- Transient model-predicted drawdown – Excellent match of observed to model-predicted time-drawdown hydrograph; less than 0.1 feet of error after two days of pumping.

Two plots showing the observed verses the predicted head values and the residual verses observed value area are presented in Figure 4-2. The plot of observed head versus predicted head should be close to a straight line for a calibrated model, and the plot of residual versus observed value should have no noticeable trend. A comparison of the observed versus predicted head values for each calibration target is presented on Table 4-1.

Overall, the model-predicted water-level elevations are generally within 5 feet of the observed value, well within the measurement error of the calibration data given the age of the dataset. The calibrated model-predicted potentiometric surface is presented on Figure 4-3. The overall pattern of the hydraulic gradient (magnitude and direction) is similar to the pattern observed in the manually generated potentiometric surface contour map (Figure 3-4). It is likely that the NRMS and ARM errors could have been further reduced by a variable conductivity field using a parameter-estimating code that better “matches the data”; however, this type of approach can yield misleading results and non-conservative predictions.

The model-predicted recharge was 6,530 AFY, meeting the 4,500 to 7,500 AFY target range. Attempts to decrease the model’s predicted Basin recharge resulted in a significant increase to model error (NRMS and ARM). This relationship between reduced model error and increased recharge to the Harper Lake Basin is further discussed within Section 5.

A breakdown of the model mass balance is presented in Appendix A. The mass balance of the model was tracked using the HydroStratigraphic Unit (HSU) feature in Groundwater Vistas. The HSU option in Groundwater Vistas is similar to the Zone Budget program from the USGS (Harbaugh, 1990) and tracks the amount of water exchanged between each user defined zone. For the model, three HSU zones were established, as described below:

- Zone 1 – Harper Lake region;
- Zone 2 – Mojave River alluvium; and
- Zone 3 – Aquifer west of Iron Mountain and west of Lockhart fault.

Finally, upon completion of the steady state model calibration activities, a transient calibration was performed to check the ability of the model to reproduce time sensitive aquifer drawdown values collected from an aquifer pumping test performed near the MSP. The groundwater model successfully reproduced the observed drawdown collected from a two (2) day aquifer pumping test performed using the Ryken well as the pumping well and the Hay Farm well as the observation well (refer to BCM Figure 1-12). The Ryken well was operated at a flow rate of 1,143 gallons per minute (gpm) for the duration of the aquifer pumping test. A storage coefficient of 0.0035 was used for Layer 1. All other model input parameters remained the same as those used in the steady state calibration. The model predicted and observed time drawdown hydrographs for the Hay Farm Observation well are presented on Figure 4-4.

5 SENSITIVITY ANALYSIS

The sensitivity of the model calibration to changes in model input values was performed in general accordance with ASTM standard D 5611 (2002). The first step was to conduct a detailed sensitivity analysis on the calibration to identify which model inputs have the most impact on the degree of calibration of the model. The second step was to qualitatively evaluate the sensitivity of the model predictions, such as the total recharge entering the Basin.

5.1 CALIBRATION SENSITIVITY ANALYSIS

Prior to using the numerical model for predictive analysis, a detailed sensitivity analysis was performed to evaluate the impact of modifying model input parameters on the model calibration. The sensitivity analysis was performed using an automated process in Groundwater Vistas, and was performed using steady-state conditions. For this analysis, each model parameter listed below was changed, one parameter at a time, to evaluate the impact of that parameter change on the statistical calibration results. The following model input parameters or boundary conditions were modified to evaluate the sensitivity of the numerical model to each model parameter individually:

- Hydraulic conductivity values (eight zones);
- GHB conductance for both reaches in the Mojave River alluvium;
- Drain Boundary conductance.

The sensitivity of each model parameter or boundary condition was evaluated by using the calibration targets in the numerical model and comparing the statistical data of each modified model run, specifically the ARM and NRMS, to the “base case” NRMS of the calibrated model. The sensitivity analysis was performed using the same pre-development conditions that were used to develop the calibrated model. Model parameters were modified, one at a time, by a range of plausible values for that parameter. All parameters included in the sensitivity analysis were modified on a scale from 0.5 to 1.5 times the base case used. A summary of model simulations performed for the sensitivity is presented below.

Model Parameter	Number of Zones or Reaches	Parameter multipliers (times base case in model)	Total Simulations Performed
Hydraulic Conductivity	8	0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, and 1.5	88
GHB Conductance	2	0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, and 1.5	22
Drain Conductance	1	0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, and 1.5	11
Total Steady-state Sensitivity Simulations Performed			121

The above table shows that the sensitivity analysis consisted of a total of 121 separate model simulations, each with only one parameter modified from the calibrated value. The impact of the parameter changes on the NRMS error of the model are presented on Figure 5-1. The impact of the parameter changes on the predicted total recharge of Harper Lake Basin are presented on Figure 5-2.

5.2 CALIBRATION SENSITIVITY ANALYSIS CONCLUSIONS

Based on the results of the sensitivity analysis, the numerical model appears relatively insensitive to most model input and boundary conditions tested. The parameter that exhibited the most sensitivity is the hydraulic conductivity of Zone 5, which corresponds to the area near the Hinkley Gap. Reducing the hydraulic conductivity by 50 percent of the base case (70 ft/day), resulted in an increase of the NRMS error to 4.8 percent, compared to 3.2 percent for the model base case. Increasing the hydraulic conductivity of Zone 5 by 50 percent also resulted in an increase in the model error to 3.8 percent. The hydraulic conductivity of Zone 4, which corresponds to the Mojave River alluvial valley, also is a sensitive parameter and produced similar changes in the model error.

The hydraulic conductivities of Zone 4 and Zone 5 are also the most sensitive parameters that impact the model predicted recharge to the Basin. As shown on Figure 5-2, the total recharge to the Basin predicted by the model varies from 4,400 acre-ft/yr to 7,700 acre-ft/yr depending on the hydraulic conductivity values selected for these two zones. When Figures 5-1 and 5-2 are reviewed concurrently, it can be seen that the model error increases significantly as the hydraulic conductivity of Zone 4 and Zone 5 is increased or decreased from the base case of the calibrated model. Therefore, the most defensible model predicted total recharge to the Basin is the base case value of 6,530 acre-ft/yr.

The other model input parameters are generally insensitive and do not significantly impact the model error or the model predicted total recharge to the Basin. It should be noted that the calibrated model parameters yielded the best compromise between the statistical match to the pre-development calibration data set and the model predicted total recharge to the Basin. The changes to model input parameters that improved the statistical match, such as hydraulic conductivity values, resulted in significant increase or decrease to predicted total Basin recharge. The results of the sensitivity analysis confirm the importance quantifying the hydraulic conductivity distribution within the aquifer.

6 PREDICTIVE ANALYSIS

Upon completion of the steady-state calibration check and model calibration sensitivity analysis, the numerical model was used for predictive analyses. The primary objective of the predictive analysis was to use the calibrated groundwater flow model to predict the hydraulic interference generated by MSP groundwater production during the 26 month construction phase and during the 30-year operations phase.

Numerical groundwater models evaluate the theoretical response of an aquifer system to a series of prescribed future stresses. It is unreasonable to expect absolute accuracy from the results of a predictive analysis using a numerical groundwater model, given the potential variability of the input parameters. Rather, the output of numerical model predictive analyses should be regarded as a reasonable approximation of future aquifer responses to the aquifer stresses simulated.

6.1 STARTING HEADS FOR PUMPING SIMULATIONS

One of the primary objectives of the model was to estimate the cone of depression that would result due to the operation of future MSP production wells. To make this type of predictive evaluation, it is necessary to subtract the pre-pumping model predicted potentiometric surface from the post pumping model predicted potentiometric surface.

The model predicted heads calculated from the calibrated non-pumping simulation were used as the starting heads for all predictive simulations presented. The model predicted drawdown presented in this document is the difference between the start heads and the model predicted heads for the various predictive simulations.

6.2 PREDICTIVE SCENARIOS - RESULTS

Two predictive scenarios were used to evaluate the impact to the aquifer hydraulic conditions due to MSP groundwater production during construction and operation. Both scenarios were evaluated using a transient version of the calibrated model. The two scenarios were:

1. 26 month construction phase. This predictive simulation was performed assuming transient conditions and a 26 month duration. Three production wells were pumped during this simulation; each at a flow a rate of 410 gpm. The predicted hydraulic interference (drawdown) is shown on Figure 6-1.
2. Thirty-year production phase. This predictive simulation was performed assuming transient conditions and a 30 year duration. Two production wells were pumped continuously during this simulation, each at a flow of 723 gpm. The predicted hydraulic interference (drawdown) is shown in Figure 6-2.

For both the construction and production phase of the MSP, the groundwater model predicts a maximum drawdown of approximately 5-feet near the production wells. This is generally consistent with the predictions presented in the BCM, which were generated using an analytical model (see BCM Figures 6-4 and 6-5). The extents and shape of the model's predicted cone of depression for both scenarios is constrained by the presence of the Lockhart Fault, indicating minimal to no recharge to MSP production wells from the aquifer, west of the fault. The model's predicted cones of depression for both simulations dissipate within a few miles of the MSP and do not cross the Lockhart Fault. The results of these simulations indicate operation of proposed MSP production wells will have no impact on the aquifer west of the Lockhart Fault and will have minimal impact on the aquifer within a two to three mile radius of the proposed wells. Due to the limited extents of the cones of depression from proposed MSP production wells, it is unlikely that MSP groundwater production during the construction and operations periods will increase Basin recharge due to underflow from neighboring groundwater basins.

7 CONCLUSIONS

The overall objective was to construct a numerical groundwater flow model based on the hydrogeologic framework presented in the BCM report that could be used as a "conceptual calculator" to evaluate:

- Recharge to the Basin;
- The hydraulic interference generated by MSP groundwater production during the 26 month construction phase; and
- The hydraulic interference generated by MSP groundwater production during the 30-year operations phase.

The groundwater model achieves the objectives listed above. A groundwater model is a computer code that solves the governing groundwater flow equations. Groundwater modeling is a state of the practice tool that is used by engineers and hydrogeologists to evaluate the theoretical response of an aquifer system to a series of prescribed future stresses. It is unreasonable to expect absolute accuracy from the results of a predictive analysis using a numerical groundwater model given the potential variability of the input parameters such as hydraulic conductivity. A thoughtfully constructed and documented model can provide a reasonable approximation of aquifer responses due to future aquifer change through the simulation process.

7.1 NUMERICAL MODEL CALIBRATION – SUMMARY

Prior to generating model predictions, the model was calibrated to ensure that it is capable of reflecting pre-development observed conditions within the Harper Lake Basin. The model was calibrated to several types of data, including: water levels collected from over 30 observation wells, a total Basin recharge target range, and drawdown observed during an aquifer pumping test (Hay Farm well). After model calibration, calibration goals identified in Section 4 were achieved. A summary of the model calibration is listed below:

- A water balance of 0.0001 percent;
- A NRMS 3.2 percent;
- An ARM of 5.0 feet, when the total head change in the model domain is approximately 300 feet;
- A randomly distributed residual vs. observed value plot, indicating no bias in model results;
- A good visual match with potentiometric surfaces developed for the study area;
- Model predicted recharge to the Basin based on maintaining pre-development hydraulic conditions is 6,530 AFY; and

- Transient model predicted drawdown – Observed time-drawdown data after a two day pumping test matches a model predicted time drawdown hydrograph; less than 0.1 feet of error after two days of pumping.

7.1.1 SENSITIVITY ANALYSIS

Prior to using the numerical model to generate predictions on future aquifer behavior, the sensitivity of the calibrated model to changes in model input values was performed. The sensitivity analyses consisted of changing model input values, one parameter at a time, to determine the impact of that parameter change on the statistical calibration results. A total of 121 sensitivity analysis simulations were performed.

Based on the results of the sensitivity analyses, the numerical model appears relatively insensitive to the majority of the model input and boundary conditions tested. However, the model is sensitive to the hydraulic conductivity of the Mojave River alluvial valley and to the hydraulic conductivity of the Hinkley Gap aquifer. As shown on Figure 5-2, the total recharge to the Basin predicted by the model varies from 4,400 acre-ft/yr to 7,700 acre-ft/yr depending on the hydraulic conductivity values selected for these two zones. The final, calibrated, hydraulic conductivity values for these two zones were selected to reduce the error within the model. If the hydraulic conductivity of either of these zones is increased or decreased from the base case of 70 ft/day, then the NRMS error within the model increases significantly in comparison to the base case of 3.2 percent. The 70 ft/day hydraulic conductivity value for these zones is consistent with the range of values for hydraulic conductivity presented in the BCM.

7.2 MODEL PREDICTION SUMMARY

As stated above, the numerical groundwater flow model has the lowest model error and best matched the observed magnitude and direction of the pre-development potentiometric surface with a total Basin recharge value of 6,530 AFY. As an example, for the model predicted total Basin recharge to match a recharge value of 5,200 AFY, the total model error would increase from a NRMS of 3.2 percent for the base case to 4.2 to 4.4 percent. Therefore, the most defensible model predicted total recharge to the Basin is the base case value of 6,530 AFY.

Two aquifer pumping scenarios were evaluated to predict the impact of potential future MSP production wells on the water levels within the aquifer. The scenarios were both simulated using transient conditions and consisted of a short term (26 month) construction period and a long term (30 year) operations period. The predicted hydraulic interference (drawdown) for the two model scenarios is shown on Figure 6-1 and Figure 6-2.

The extents and shape of the groundwater model predicted cones of depression for both scenarios is constrained by the presence of the Lockhart Fault, indicating there is minimal to no recharge to MSP production wells from the aquifer, west of the fault. The model's predicted cones of depression for both simulations dissipate within a few miles of the MSPand do not cross the Lockhart Fault. The results of these simulations indicate that the operation of future production wells associated with the MSP will have no impact on the aquifer west of the Lockhart Fault and will have minimal impact on the aquifer within a two to three mile radius of the wells. Due to the limited extents of the cones of depression from proposed MSP production wells, it is unlikely that MSP groundwater production during the construction and operations periods will increase Basin recharge due to underflow from neighboring groundwater basins.

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TABLES

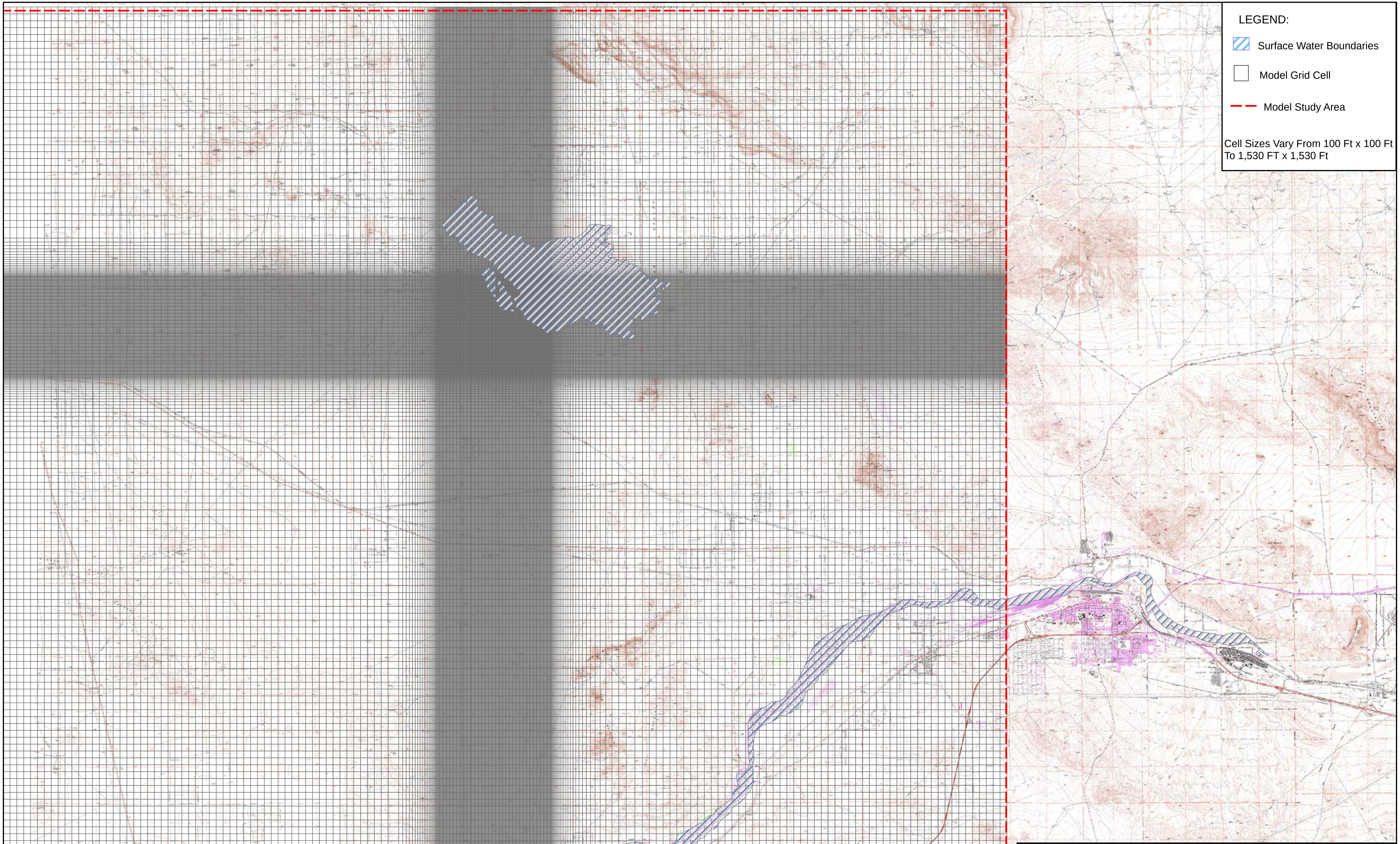
Table 4-1
Water Level Calibration Targets and Steady State Calibration Results
Mojave Solar Project
Hinkley, California

Well ID	Easting (CA State Plane, feet)	Northing (CA State Plane, feet)	Observed Head (ft msl)	Computed Head (ft msl)	Residual Head Difference (feet)
2	6,754,735.12	2,209,610.17	2,018.00	2,021.00	-3.00
4	6,760,999.10	2,192,246.29	2,013.00	2,021.67	-8.67
5	6,768,898.45	2,192,395.04	2,012.00	2,021.09	-9.09
6	6,806,146.57	2,163,087.60	2,148.00	2,148.81	-0.81
7	6,792,507.34	2,210,693.07	2,010.00	2,024.46	-14.46
8	6,790,008.35	2,208,260.72	2,011.00	2,023.87	-12.87
9	6,796,594.58	2,198,886.73	2,035.00	2,028.54	6.46
10	6,791,774.31	2,193,233.45	2,019.00	2,026.01	-7.01
11	6,801,936.87	2,193,655.50	2,040.00	2,038.79	1.21
13	6,807,567.93	2,188,168.83	2,060.00	2,057.89	2.11
14	6,808,611.96	2,173,719.10	2,108.00	2,109.24	-1.24
15	6,812,532.60	2,177,517.57	2,103.00	2,097.44	5.56
16	6,811,444.15	2,170,942.45	2,122.30	2,119.83	2.47
17	6,804,974.09	2,160,808.01	2,161.00	2,153.02	7.98
18	6,807,490.19	2,161,857.22	2,156.00	2,150.07	5.93
19	6,799,923.65	2,144,882.19	2,193.10	2,193.44	-0.34
20	6,809,699.56	2,150,243.75	2,176.10	2,178.69	-2.59
21	6,809,721.42	2,147,587.04	2,178.10	2,183.43	-5.33
22	6,807,174.58	2,143,635.48	2,199.70	2,193.28	6.42
23	6,809,753.77	2,143,656.59	2,188.75	2,190.42	-1.67
24	6,811,050.77	2,146,396.96	2,195.50	2,184.08	11.42
25	6,821,947.17	2,159,118.44	2,158.90	2,158.65	0.25
26	6,821,568.33	2,154,449.90	2,165.70	2,164.12	1.58
27	6,810,808.98	2,175,620.87	2,109.10	2,103.55	5.55
28	6,810,926.87	2,164,994.18	2,141.50	2,136.16	5.34
30	6,806,044.33	2,159,783.37	2,151.90	2,155.16	-3.26
32	6,804,517.37	2,194,168.03	2,037.70	2,043.20	-5.50
33	6,804,537.05	2,191,729.62	2,052.70	2,046.14	6.56
34	6,792,394.62	2,193,672.29	2,028.10	2,026.60	1.50
35	6,805,967.99	2,188,829.48	2,056.94	2,053.18	3.76
Well_52	6,828,607.43	2,156,629.34	2,157.00	2,160.88	-3.88
Well_53	6,832,960.11	2,155,813.21	2,154.00	2,159.89	-5.89

Statistical Analysis of Residuals	
Residual Mean	-0.36
Residual Standard Deviation	6.11
Sum of Squares	1,197.77
Absolute Residual Mean (ARM)	4.99
Minimum Residual	-14.46
Maximum Residual	11.42
Range in Target Values	189.70
NRMS	3.22%

Note:
Calibration Targets - Pre-Development values from Thompson, 1929 (Plate 17, pg 271)

FIGURES



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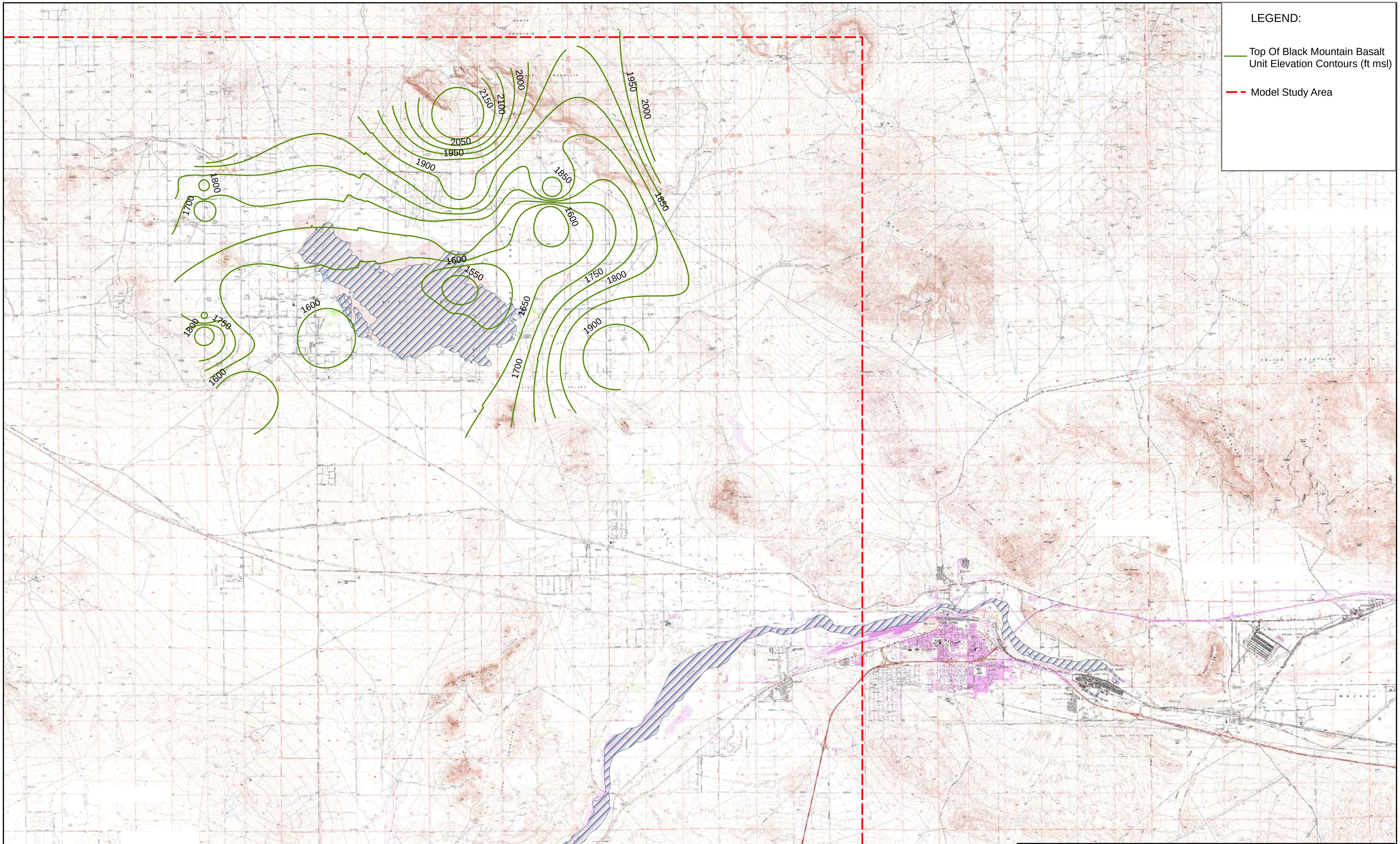
JOB NO. 271643
DATE July 2009
FILE Fig 3-1.mxd
PROJECT Mojave Solar LLC

TITLE Figure 3-1: Study Area and Model Grid



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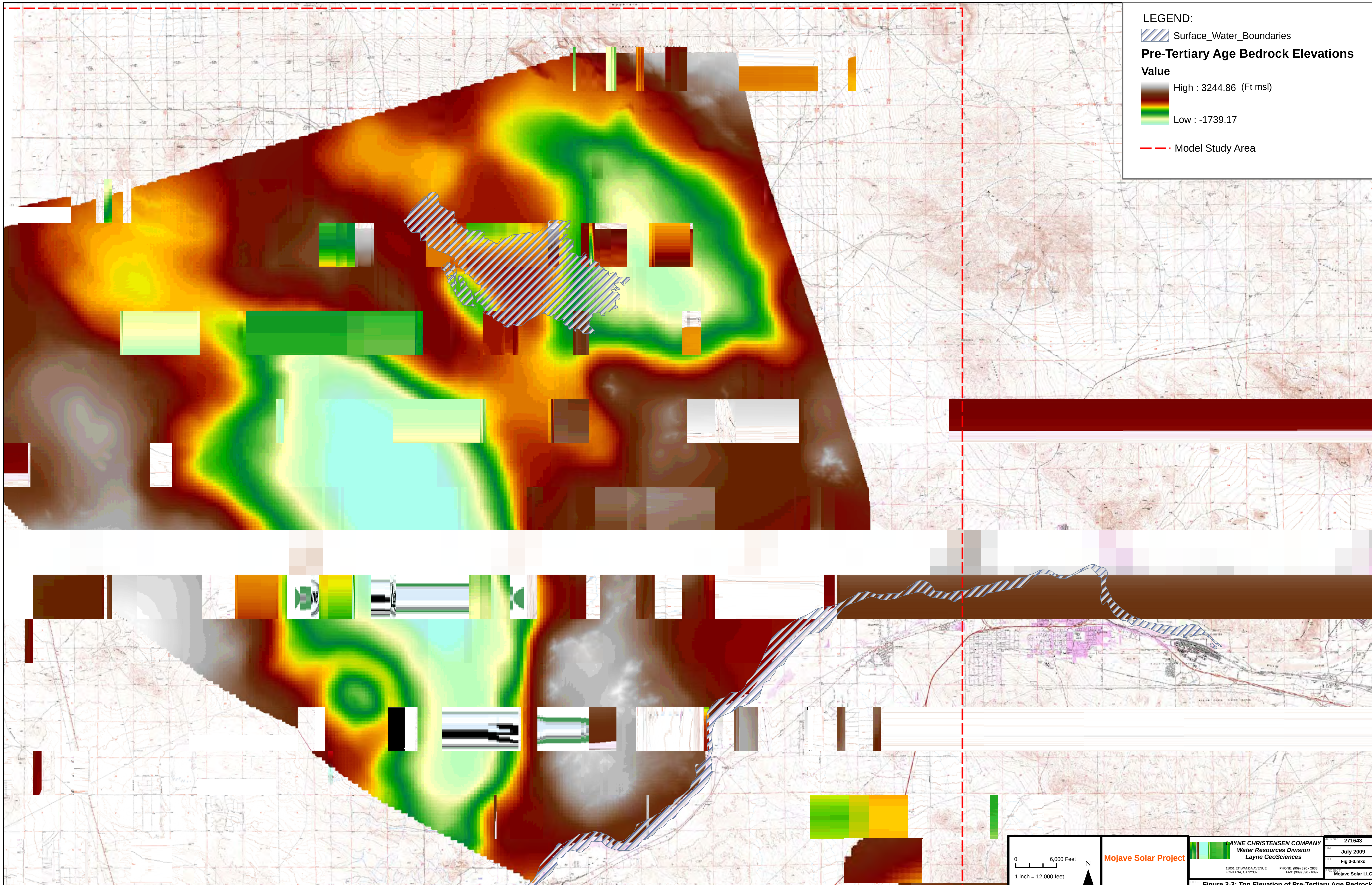
JOB NO.	271643
DATE	July 2009
FILE	Fig 3-2.mxd
PROJECT	Mojave Solar LLC

TITLE Figure 3-2: Top Elevation of Black Mountain Basalt Unit



TITLE Figure 3-3: Top Elevation of Pre-Tertiary Age Bedrock

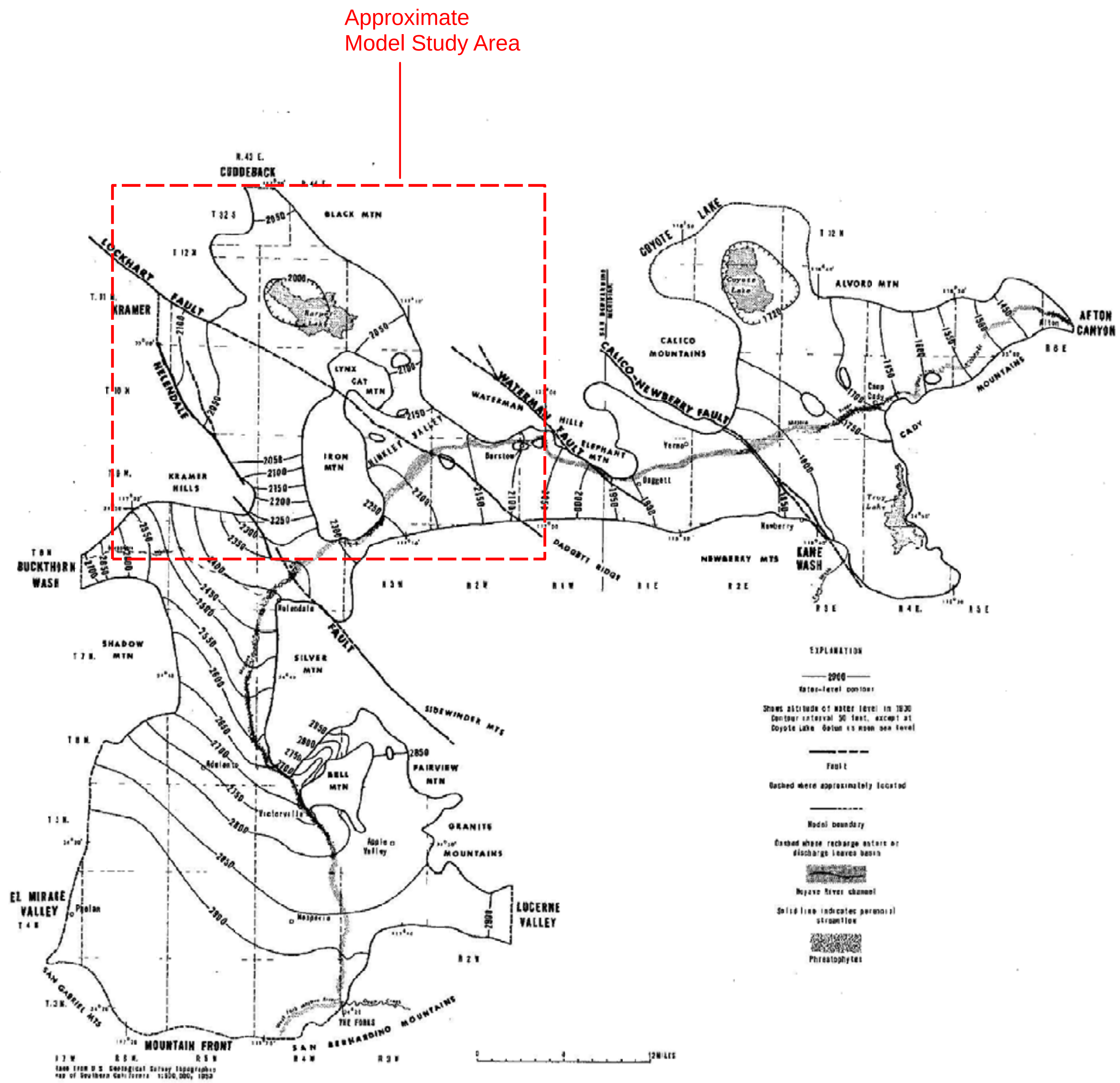


FIGURE 14.--Ground-water level, 1930.

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Fig 3-4mxd
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Figure 3-4 Pre-Development Study Area Potentiometric Surface Map

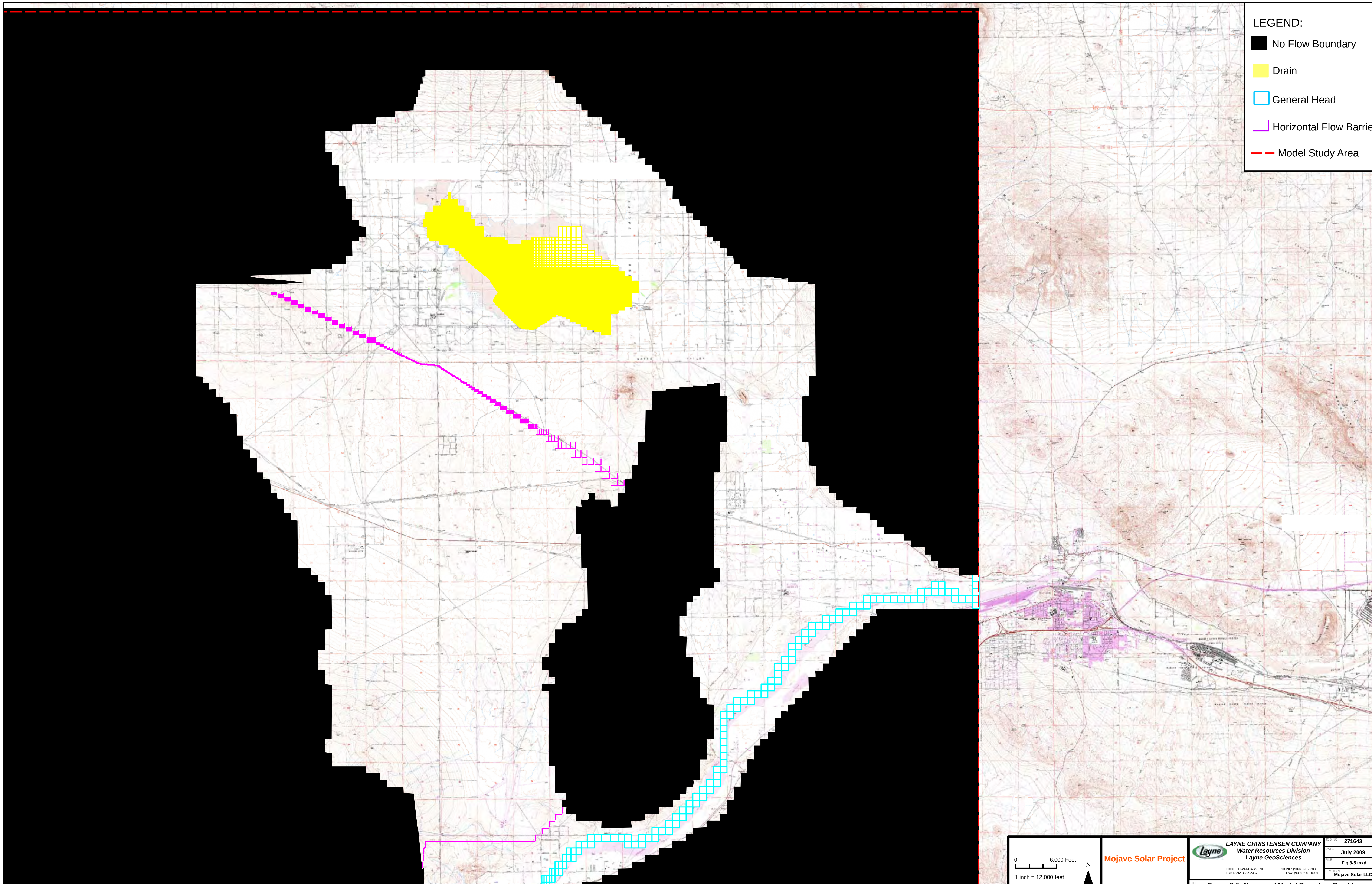
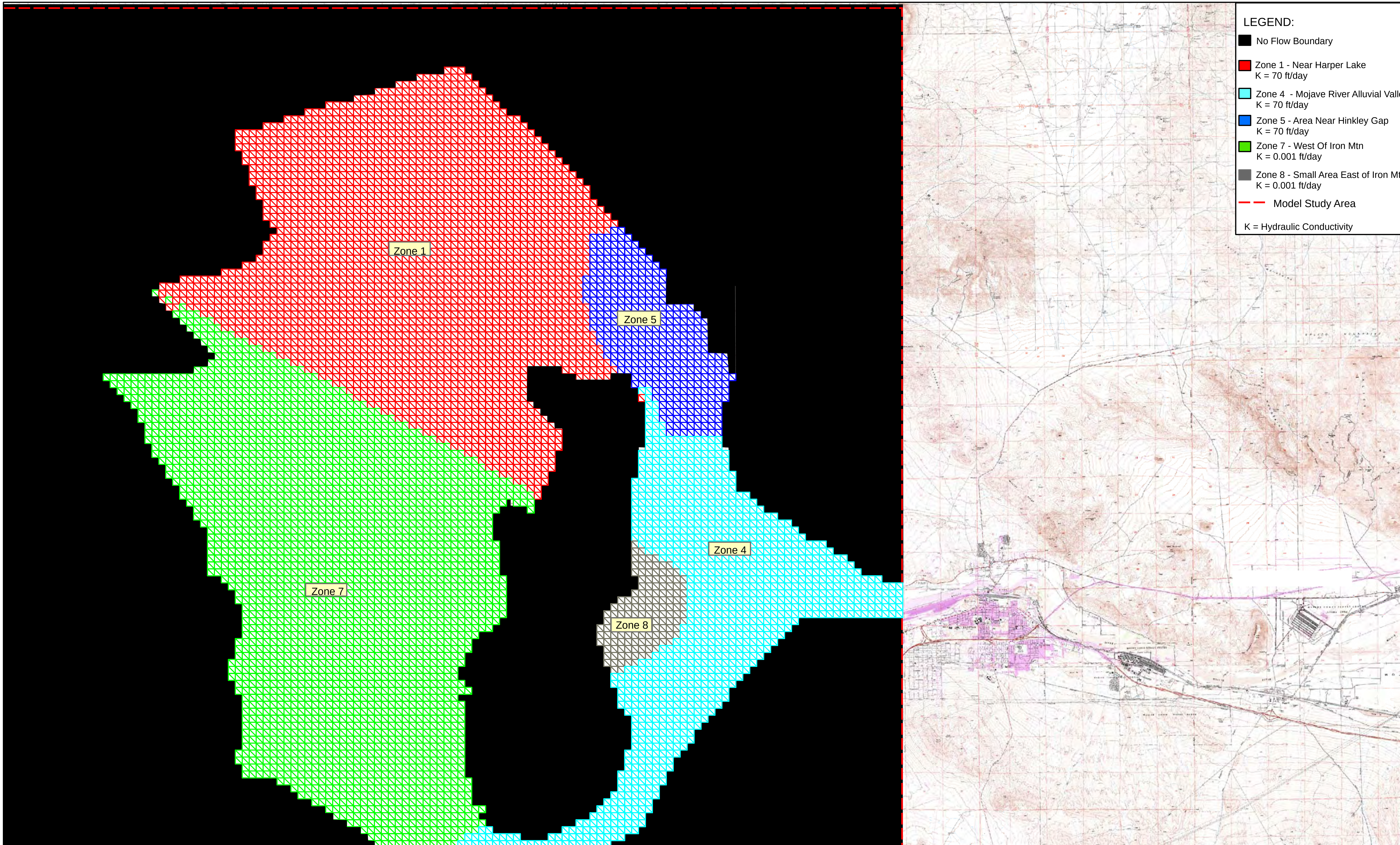


Figure 3-5: Numerical Model Boundary Conditions



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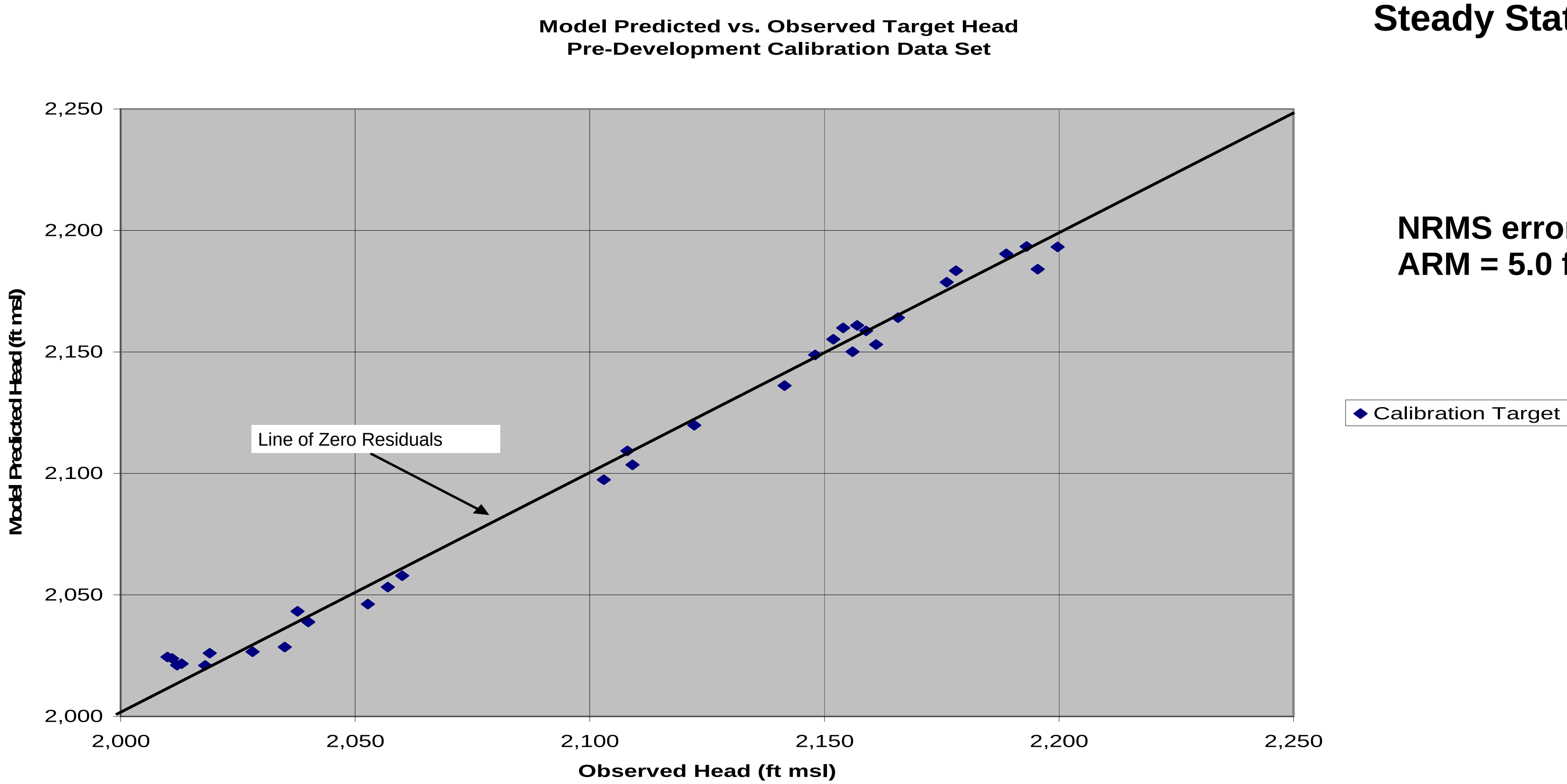
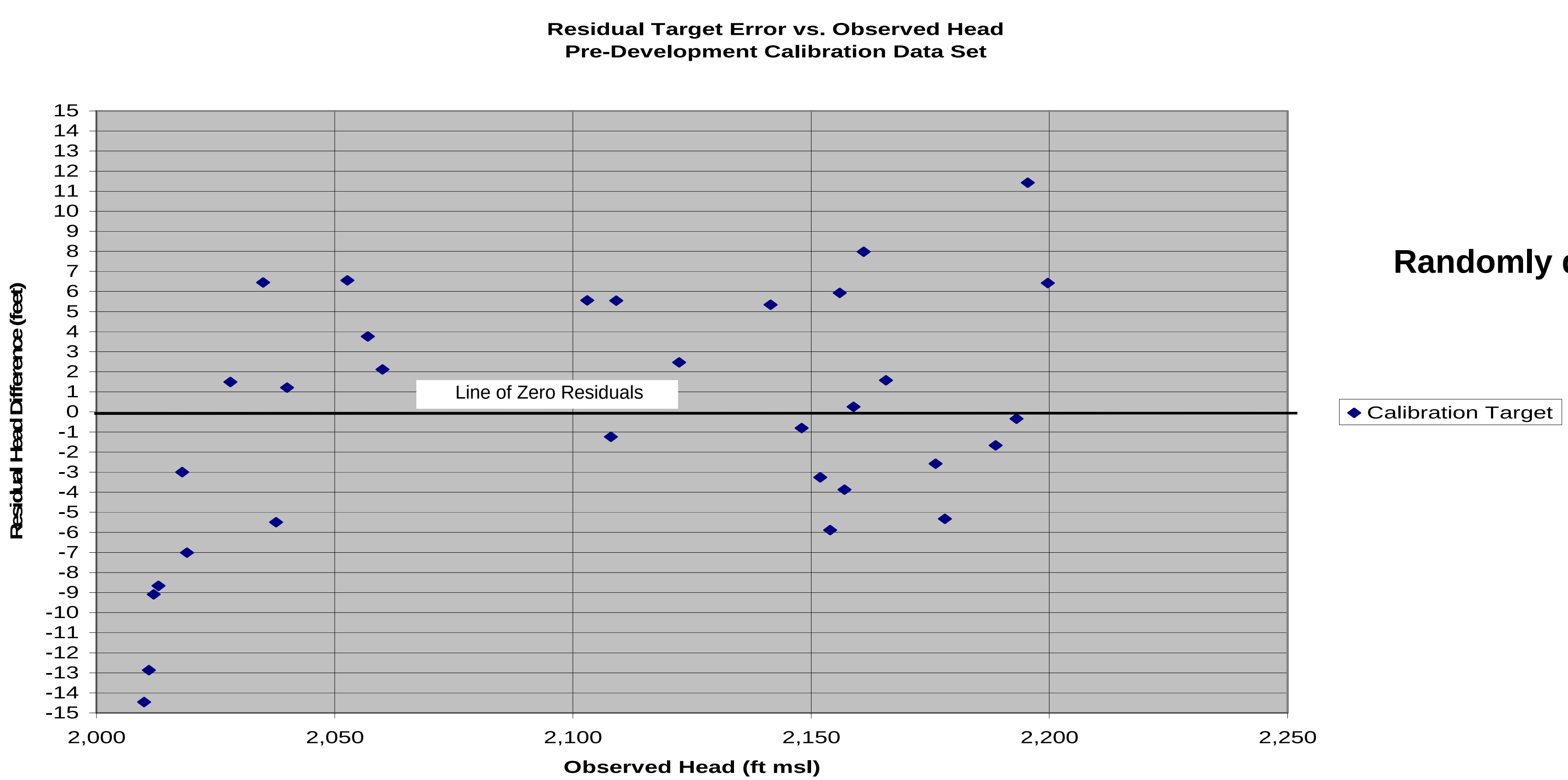
JOB NO.	271643
DATE	July 2009
FILE	Fig 4-1.mxd
PROJECT	Mojave Solar LLC

TITLE Figure 4-1 Final Hydraulic Conductivity Distribution (Layer 1)

Steady State Model Calibration Results - Distribution of Residuals



NRMS error = 3.2%
ARM = 5.0 feet



Randomly distributed error, indicating no bias in model results

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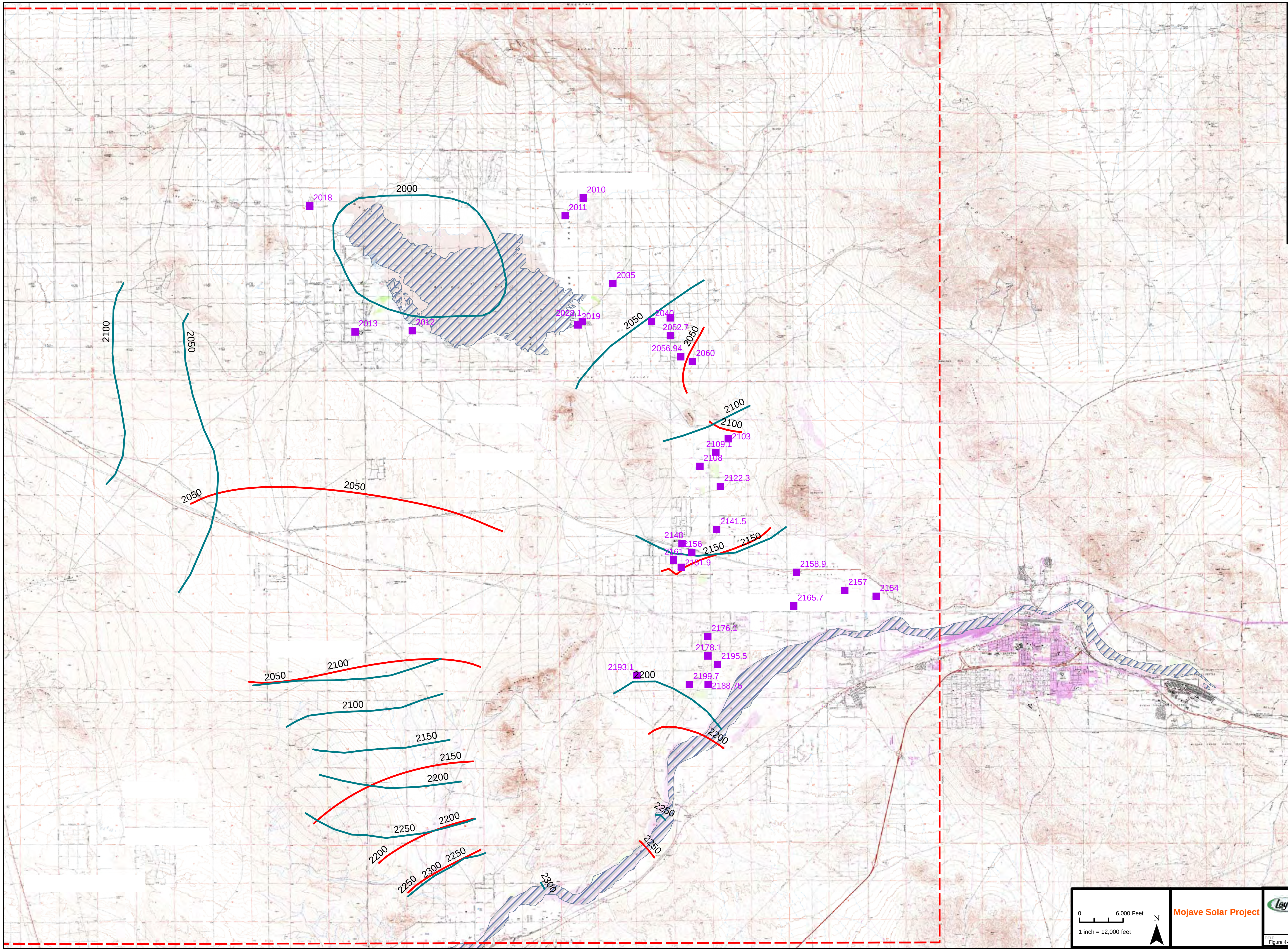
	TITLE Figure 4-2: Steady State Model Calibration Results	



LEGEND:

Surface Water Boundaries

2100 Observed Pre-Development Water Surface (ft msl) (Hardt, 1971)

2050 Model Predicted Potentiometric Surface (ft msl)

2010 Pre-Development Calibration Target With Observed Potentiometric Surface Elevation (ft msl)

Model Study Area

0 6,000 Feet

1 inch = 12,000 feet

N

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Water Resources Division
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JOB NO. 271643

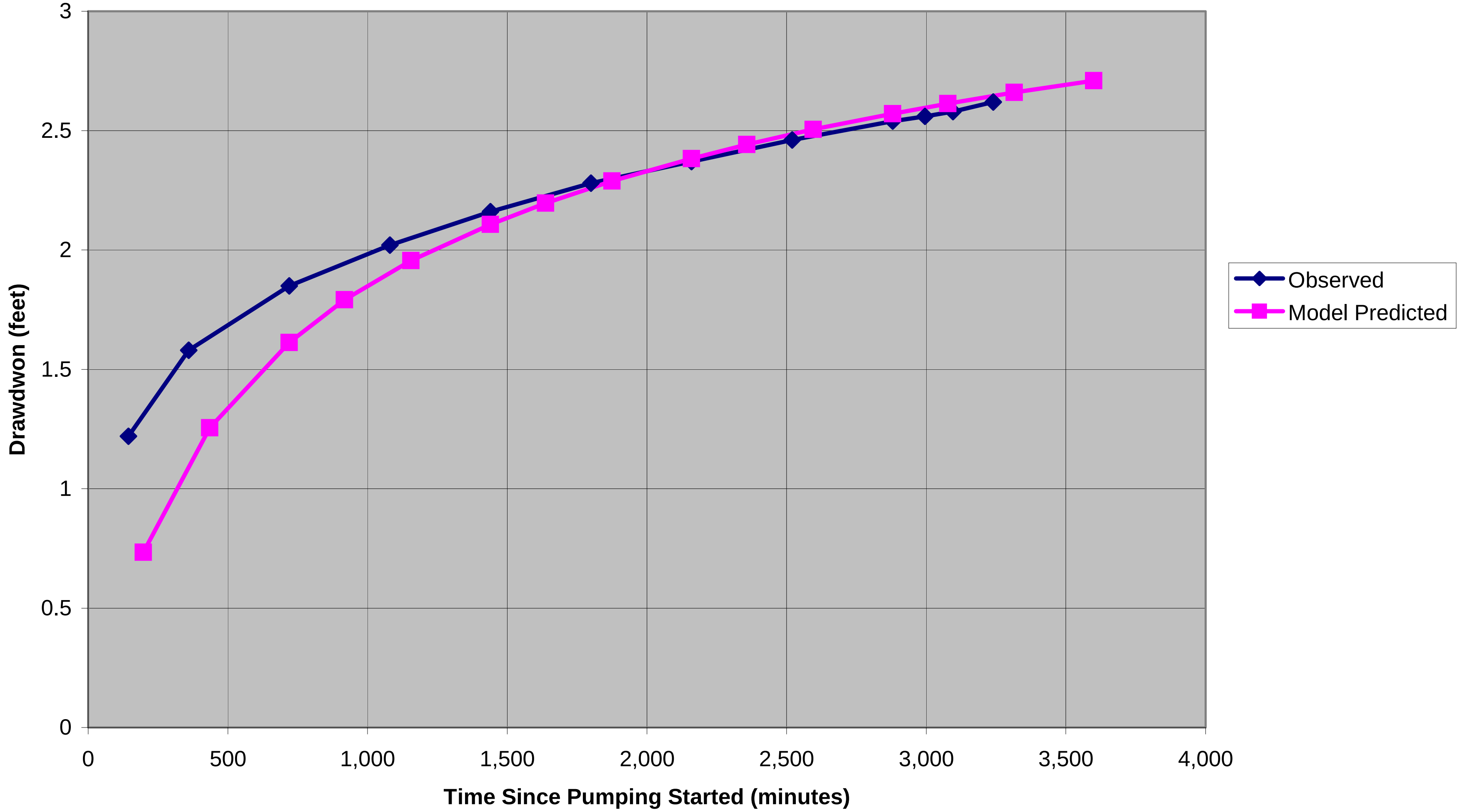
DATE July 2009

FILE Fig 4-3.mxd

PROJECT Mojave Solar LLC

TITLE Figure 4-3 Model Predicted vs Observed Pre-Development Potentiometric Surface (Layer 1)

Transient Calibration Results – Plot of Model Predicted vs. Observed Time   Drawdown Hydrograph for Ryken Well Aquifer Test



Notes:
1) Observed Drawdown Collected from Hay Farm Well (750 ft from pumping well)
2) Pumping Test Conducted at Q = 1,143 gpm

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	Figure 4-4: Transient Calibration Results	

Sensitivity Analysis Results –
Impact of Parameter Changes on Model NRMS Error

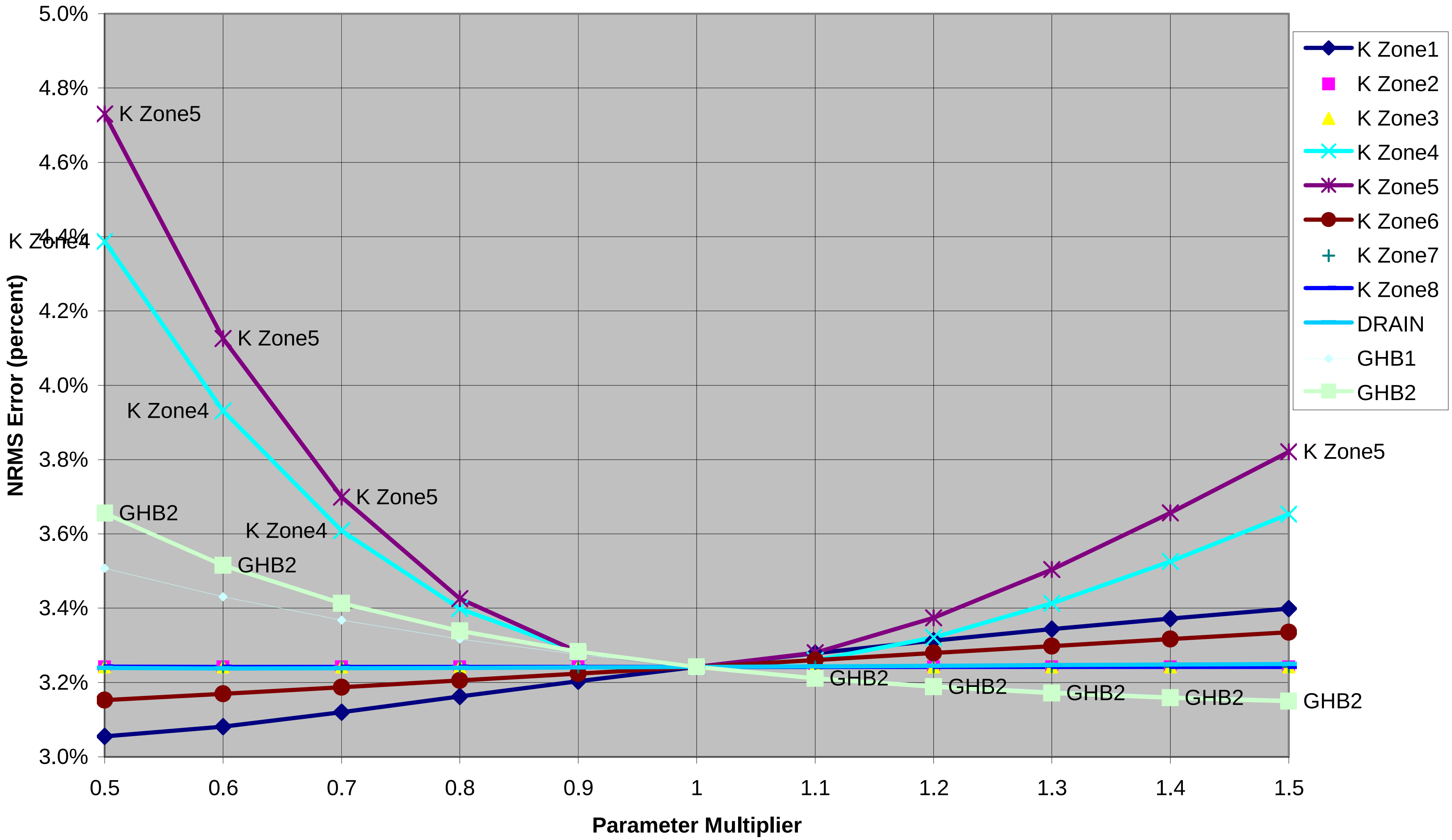

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	Figure 5-1: Sensitivity Analysis Results	

Sensitivity Analysis Results -
Impact of Parameter Changes on Model Predicted Recharge to Harper Lake Basin

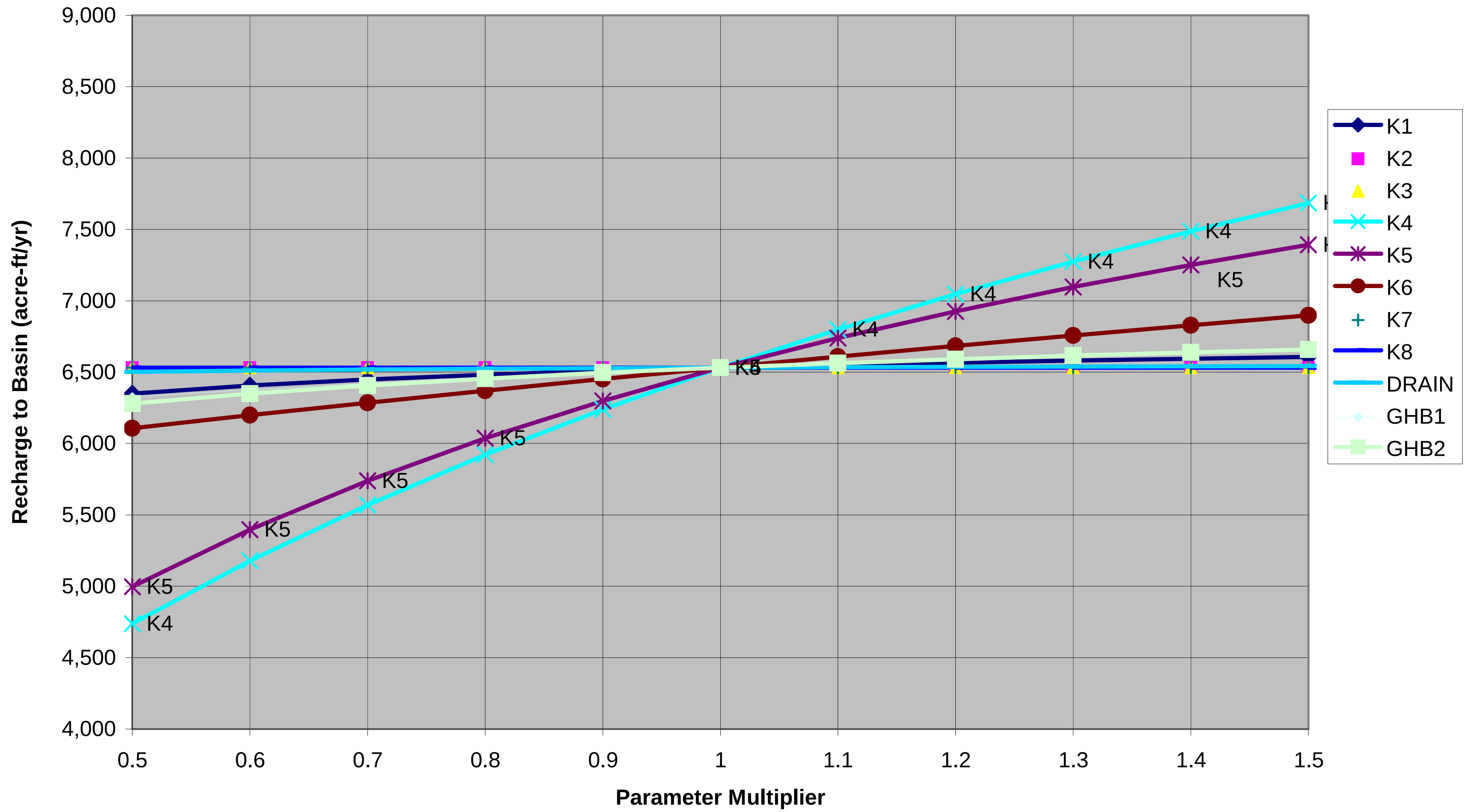

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	Figure 5-2: Sensitivity Analysis Results	

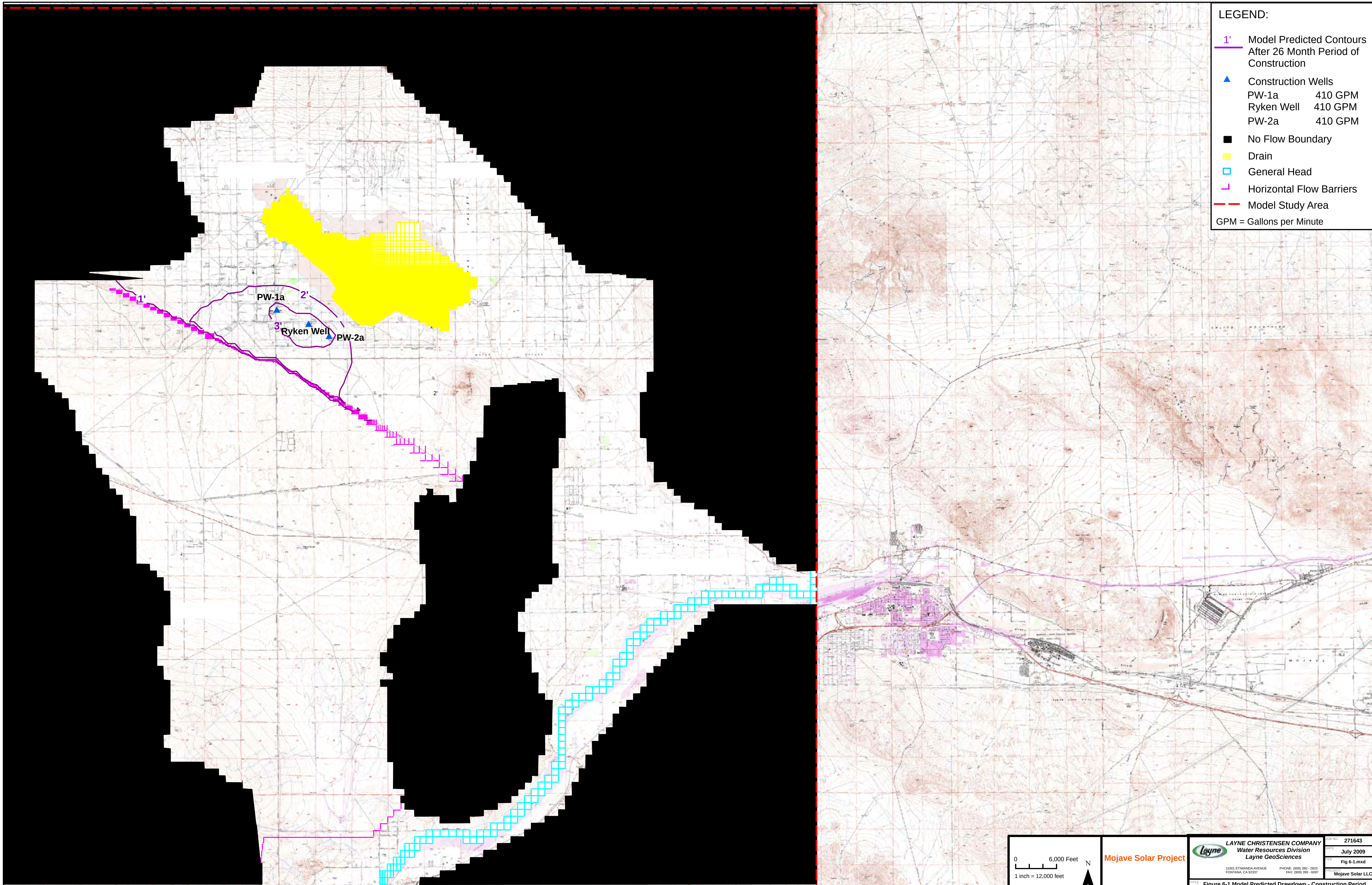
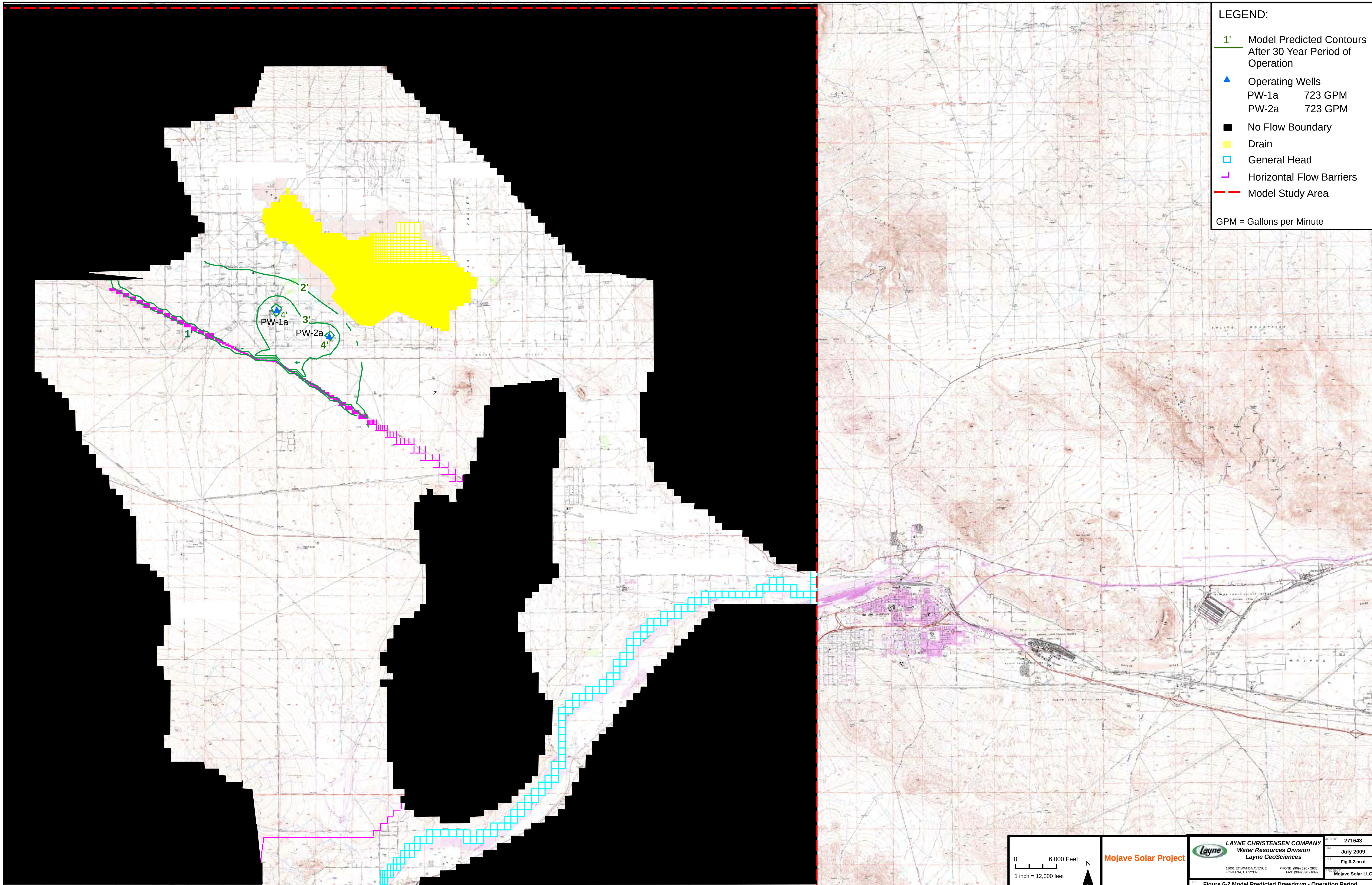


Figure 6-1 Model Predicted Drawdown - Construction Period



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TITLE Figure 6-2 Model Predicted Drawdown - Operation Period

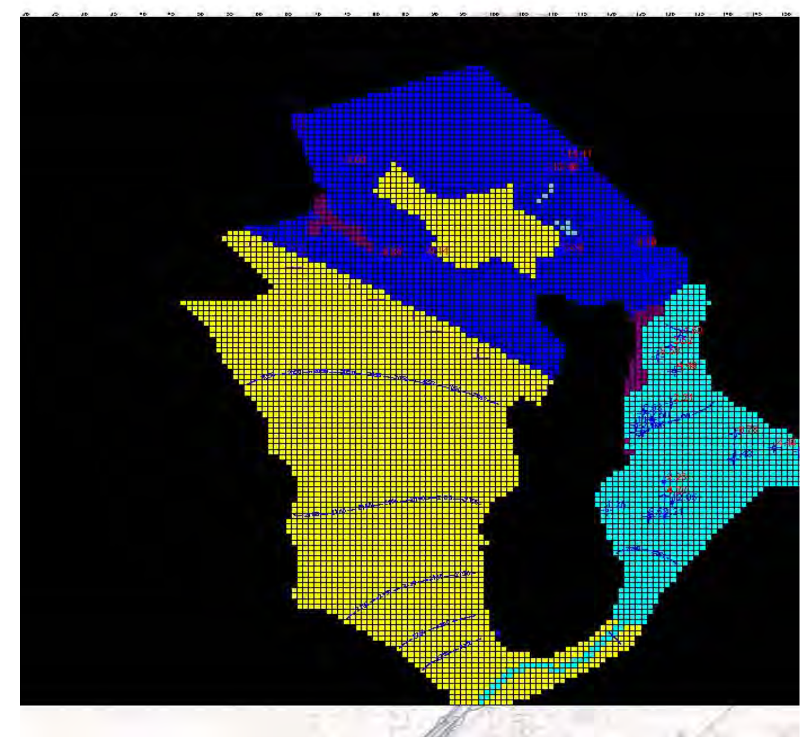
APPENDIX A

Calibrated Steady State Mass Balance

Calibrated Groundwater Model
Mass Balance
by Hydrostratigrahic Units

Summary of HSU Zone Number	1	
Flows Within HSU	Inflow (ft3/day)	Outflow (ft3/day)
Constant Head	0.00E+00	0.00E+00
River	0.00E+00	0.00E+00
Drain	0.00E+00	7.77E+05
GHB	0.00E+00	0.00E+00
Well	0.00E+00	0.00E+00
Stream	0.00E+00	0.00E+00
Lake	0.00E+00	0.00E+00
Recharge	0.00E+00	0.00E+00
ET	0.00E+00	0.00E+00
Storage	0.00E+00	0.00E+00

Flows Between HSUs			Inflow	Outflow
HSU Number	Inflow	Outflow	acre ft/yr	acre ft/yr
HSU Zone 2	7.77E+05	0.00E+00	6,528.98	0.00
HSU Zone 3	5.00E+04	4.98E+04	419.66	418.17
TOTAL FLOWS	8.27E+05	8.27E+05		
Error	-4.85E-04			



Summary of HSU Zone Number	2	
Flows Within HSU	Inflow	Outflow
Constant Head	0.00E+00	0.00E+00
River	0.00E+00	0.00E+00
Drain	0.00E+00	0.00E+00
GHB	3.74E+05	1.34E+05
Well	0.00E+00	0.00E+00
Stream	0.00E+00	0.00E+00
Lake	0.00E+00	0.00E+00
Recharge	0.00E+00	0.00E+00
ET	0.00E+00	0.00E+00
Storage	0.00E+00	0.00E+00

Flows Between HSUs			Inflow	Outflow
HSU Number	Inflow	Outflow	acre ft/yr	acre ft/yr
HSU Zone 1	0.00E+00	7.77E+05	0.00	6,528.98
HSU Zone 3	5.37E+05	0.00E+00	4,513.16	0.00
TOTAL FLOWS	9.11E+05	9.11E+05		
Error	-2.18E-06			

Color	**Hydrostratigraphic Unit**
Yellow	**Zone 3**
Aqua Blue	**Zone 2**
Dark Blue	**Zone 1**

Summary of HSU Zone Number	3	
Flows Within HSU	Inflow	Outflow
Constant Head	0.00E+00	0.00E+00
River	0.00E+00	0.00E+00
Drain	0.00E+00	0.00E+00
GHB	5.37E+05	0.00E+00
Well	0.00E+00	0.00E+00
Stream	0.00E+00	0.00E+00
Lake	0.00E+00	0.00E+00
Recharge	0.00E+00	0.00E+00
ET	0.00E+00	0.00E+00
Storage	0.00E+00	0.00E+00

Flows Between HSUs			Inflow	Outflow
HSU Number	Inflow	Outflow	acre ft/yr	acre ft/yr
HSU Zone 1	4.98E+04	5.00E+04	418.17	419.66
HSU Zone 2	0.00E+00	5.37E+05	0.00	4,513.16
TOTAL FLOWS	5.87E+05	5.87E+05		
Error	5.34E-05			